AOD-TR-76-002

CLOSED DIE FORGING OF POWDER METAL PREFORMS

COMPARISON OF P/M FORGING SYSTEMS

FINAL REPORT

FRANK T. LALLY
TRW Inc.
and
J. RONALD RUSSELL
Rock Island Arsenal

DECEMBER 1976

U.S. ARMY ARMAMENT COMMAND

PREPARED BY

TRW INC.
and
ROCK ISLAND ARSENAL

DISTRIBUTION STATEMENT
Approved for public release; distribution unlimited.

ARSENAL OPERATIONS DIRECTORATE
ROCK ISLAND ARSENAL
ROCK ISLAND, ILLINOIS 61201

```
--     1    OF     1
-- 1 -  AD NUMBER: A036054
-- 2 -  FIELDS AND GROUPS: 11/6
-- 3 -  ENTRY CLASSIFICATION:   UNCLASSIFIED
-- 5 -  CORPORATE AUTHOR: TRW INC  CLEVELAND OHIO MATERIALS TECHNOLOGY
-- 6 -  UNCLASSIFIED TITLE:     CLOSED DIE FORGING OF POWDER METAL PERFORMS
--      COMPARISON OF P/M FORGING SYSTEMS.
-- 8 -  TITLE CLASSIFICATION:   UNCLASSIFIED
-- 9 -  DESCRIPTIVE NOTE: FINAL REPT.,
--10 -  PERSONAL AUTHORS: LALLY,FRANK T. ;RUSSELL,J. RONALD ;
--11 -  REPORT DATE:       DEC    , 1976
--12 -  PAGINATION:     62P   MEDIA COST:  $  6.00 PRICE CODE:   AA
--14 -  REPORT NUMBER:     ER-7774-F
--15 -  CONTRACT NUMBER:   DAAA08-75-C-0070
--18 -  MONITOR ACRONYM:   AOD
--19 -  MONITOR SERIES:    TR-76-002
--20 -  REPORT CLASSIFICATION:  UNCLASSIFIED
--23 -  DESCRIPTORS:       *POWDER METALLURGY, *FORGING, DIES,
--      PRESSES(MACHINERY), MACHINE GUNS, PUNCHING MACHINES, GUN COMPONENTS,
--      DEFORMATION
--24 -  DESCRIPTOR CLASSIFICATION:    UNCLASSIFIED
--27 -  ABSTRACT:   THE PROJECT WAS AIMED AT ESTABLISHING THE POTENTIAL
--         <<P FOR NEXT PAGE>> OR <<ENTER NEXT COMMAND>>
                                              *MSG RECEIVED*
1a ROW=24 COL= 01          <Ctrl>H For Help                              N  Poll
```

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER AOD-TR-76-002	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) CLOSED DIE FORGING OF POWDER METAL PREFORMS COMPARISON OF P/M FORGING SYSTEMS		5. TYPE OF REPORT & PERIOD COVERED Final Report
		6. PERFORMING ORG. REPORT NUMBER 6747495
7. AUTHOR(s) F. T. Lally & J. R. Russell		8. CONTRACT OR GRANT NUMBER(s) DAAA08-75-C-0070
9. PERFORMING ORGANIZATION NAME AND ADDRESS TRW, Inc. Materials Technology Cleveland, Ohio 44117		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS AMS Code 3297.06.7495
11. CONTROLLING OFFICE NAME AND ADDRESS CDR, Rock Island Arsenal Arsenal Operations Directorate, SARRI-AOR Rock Island, Illinois 61201		12. REPORT DATE Dec 1976
		13. NUMBER OF PAGES 53
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

1. Powder Metal Forgings
2. M85 Accelerator
3. Minimum Deformation Tooling
4. Mechanical Crank Type Press

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The project was aimed at establishing the potential usefulness of existing standard forge shop equipment for producing precision powder metal (P/M) forgings. The accelerator for the M85 machine gun was used as the demonstration component. The minimum deformation type tooling for hydraulic press forging the accelerator was adapted for service in a mechanical crank type press and a steam drop forging hammer.

A die set was constructed which provided hydraulic cushions to absorb the excess force generated during forging. The die set also provided an ejection mechanism to recover the completed forging and incorporated provisions for accurate alignment of punch and die.

A number of ordnance components were identified as candidates for P/M forgings and facility requirements were defined. The mechanical press was found to be superior to either the hydraulic press or steam drop hammer for producing this type of precision forging.

PREFACE

This project was accomplished as part of the U. S. Army manufacturing technology program. The primary objective of this program is to develop, on a timely basis, manufacturing processes, techniques, and equipment for use in production of Army materiel.

The final technical report was prepared by Mr. Frank T. Lally of the Materials Technology Division, TRW Inc., Cleveland, OH 44117, in compliance with Contract DAAA08-75-C-0070.

This contract with TRW Inc. was conducted under direction of the Arsenal Operations Directorate, Rock Island Arsenal, with Mr. J. R. Russell as project engineer. At TRW, the project engineer was Mr. F. T. Lally and Mr. C. R. Cook was the program manager. The TRW report number is ER-7774-F.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

The forging of metal powder preforms (P/M forging) is a cost effective process for production of small forged components. The chief benefits of the process are achieved through high material utilization and the elimination of many machining operations. It has been shown at TRW on recently completed Army programs[1] that the properties of P/M forgings are primarily process dependent. It has also been demonstrated that by the proper selection of process parameters P/M forgings can be produced with ductility and impact properties comparable to wrought materials and suitable for ordnance components.

The purpose of the subject program was to adapt the P/M forging process to existing forging shop equipment, to define the required modifications and to establish the limitations and cost benefits of the process.

The specific objectives were:

1. Identify components which can be beneficially forged by the P/M process.

2. Define the problems involved in adapting the P/M forging process to existing forge shop equipment such as hydraulic and mechanical presses, hammers or presses specifically designed for P/M forging.

3. Compare the quality and cost of a demonstration component produced by optimized parameters by hydraulic and mechanical press forging and by hammer forging.

4. Prepare specifications which define the process and equipment options for producting P/M forged components for Army use.

---

(1) F. T. Lally, I. J. Toth and J. DiBenedetto, "Forged Metal Powder Products", U. S. Army Technical Report SWERR-TR-72-51.

2.0 PROGRAM OUTLINE

The program was designed to evaluate the advantages and disadvantages of using various types of forging equipment for a P/M forging process suitable for the production of critical weapon components. Hydraulic, hammer and mechanical presses were evaluated using the tooling and building on the experience generated on prior Army contracts.

The program was based on the following guidelines:

1. The accelerator for the M85 machine gun was selected as the demonstration component.

2. 4600 prealloyed powder blended with sufficient carbon to form the 4640 composition was used as the material.

3. Since the effects of process parameters had been established, an evaluation of process parameters was not performed.

4. Process parameters were selected to produce a high quality product capable of meeting all metallurgical and dimensional specifications.

The component selected for the program was the accelerator for the M85-50 caliber machine gun, P/N 7790977. The drawing for this part is presented in Figure 1. The process and tooling for producing the accelerator had been developed on a prior army sponsored program. The process employed a minimum deformation type preform of 4600 prealloyed powder sintered and forged to near-theoretical density. The parameters used to produce the forged accelerator are defined as follows:

Material - 4600 prealloyed powder with a minus 80 mesh particle size, blended with .7 w/o zinc stearate and sufficient graphite to form the 4640 composition (.48 w/o).

Compacting - Preform densities of 80 to 85% of theoretical 6.3 to 6.6 g/cc) achieved by 30 TSI compacting pressure.

Sintering - A sintering cycle of 2200°F for 60 minutes in hydrogen

Forging - Heat preforms to 2200°F in a hydrogen atmosphere. Forge at 40 TSI with a minimum die temperature of 400°F. Lubricate dies with a graphite-water spray.

The metallurgical quality was specified by MIL-F-45961 and the dimensional specifications supplied by the part drawing presented as Figure 1.

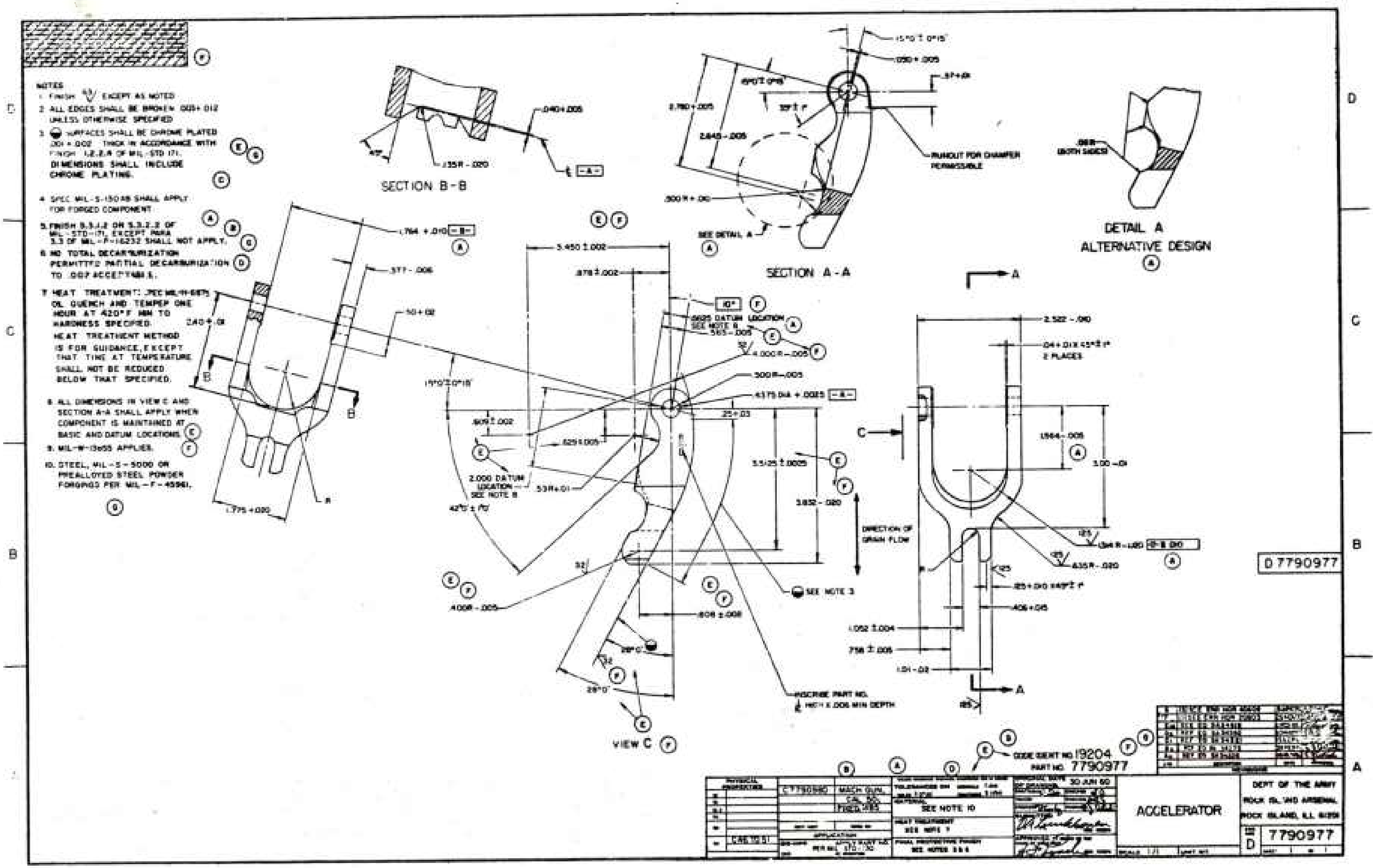


Figure 1. Accelerator for the M85 Model 50 Caliber Machine Gun.

The minimum deformation process, also called hot coining, hot pressing or hot densification, uses a preform which closely resembles the forged product. The material is subjected to very little deformation, and the forging action is primarily one of consolidation with virtually no metal flow taking place.

The preform configuration used to produce the accelerator is illustrated in Figure 2. The contours of the preform are somewhat simplified from the finished part but contain the essential elements of the forged part contour. The configuration in the plan view is established by the finished part contours using a 0.020 inch clearance envelope between the preform outline and the forging die. The shape of the preform and the close fit in the forging die provide for accurate location of the preform in the forging die. The preform dimensions in the vertical direction were estimated initially from the volume requirements of the forging. The preform configuration was optimized by forging preforms using the specified conditions of forging pressure and temperature (to insure complete densification) and measuring the resultant forgings. The indicated modifications were incorporated into the preforms and the process repeated until acceptable forgings were generated.

The tooling used for compacting the preform, shown schematically in Figure 3, is provided with individual adjustments to control the volume of material in various sections of the preform. The tooling, designed to operate at 30 TSI, produces a preform density of 85% which has been shown to be adequate for forging.

Preforms were compacted from 4600 powder blended with .48% graphite and .75% zinc stearate. Compacted preforms were sintered at 2200°F for 60 minutes in a hydrogen atmosphere. The furnace used for sintering was a 10-inch deep x 12-inch diameter induction heated furnace. Using commercial grade hydrogen with a nominal purity of 99.5%, a dew point ranging from -15 to -30°F was achieved. The sintering treatment reduced the oxygen content from 1500 PPM in the raw powder to 200 PPM or less in the sintered product.

The tooling used for forging preforms is of the three-piece type consisting of a ring-type die and upper and lower punches. Shown in Figure 4 prior to installation, the tooling is designed to produce a one-blow forging of the configuration shown in Figure 5. The as-forged configuration requires minimal subsequent machining to meet the requirements of the part drawing.

Finishing the forged accelerators to meet the part drawing dimensional and metallurgical specifications required the following sequence of operations:

a. Normalize.

b. Hand straighten the 2.522 inch dimension.

c. Drill and ream the 0.4375 inch diameter hole.

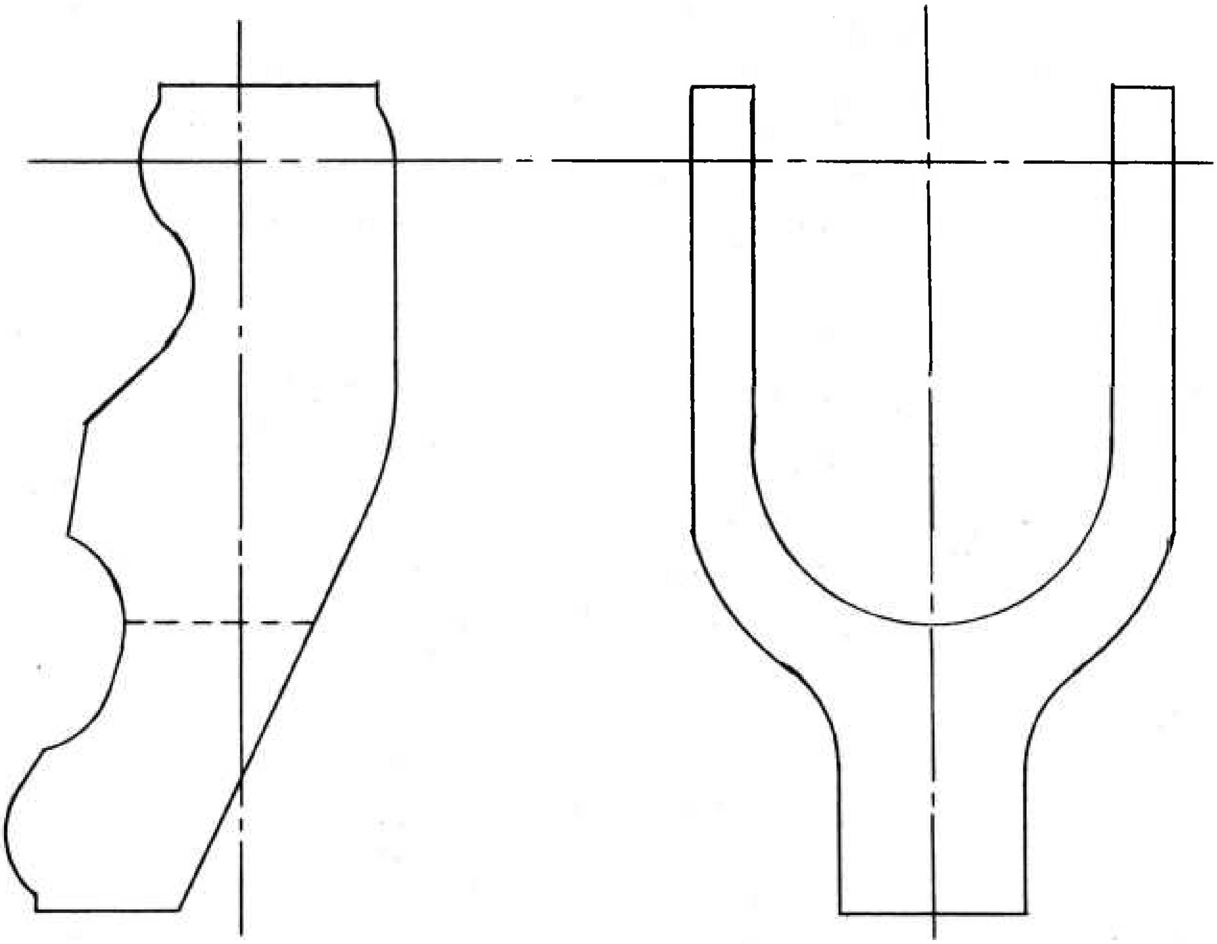


Figure 2. Preform Configuration Used For Forging the Accelerator.

5704 c

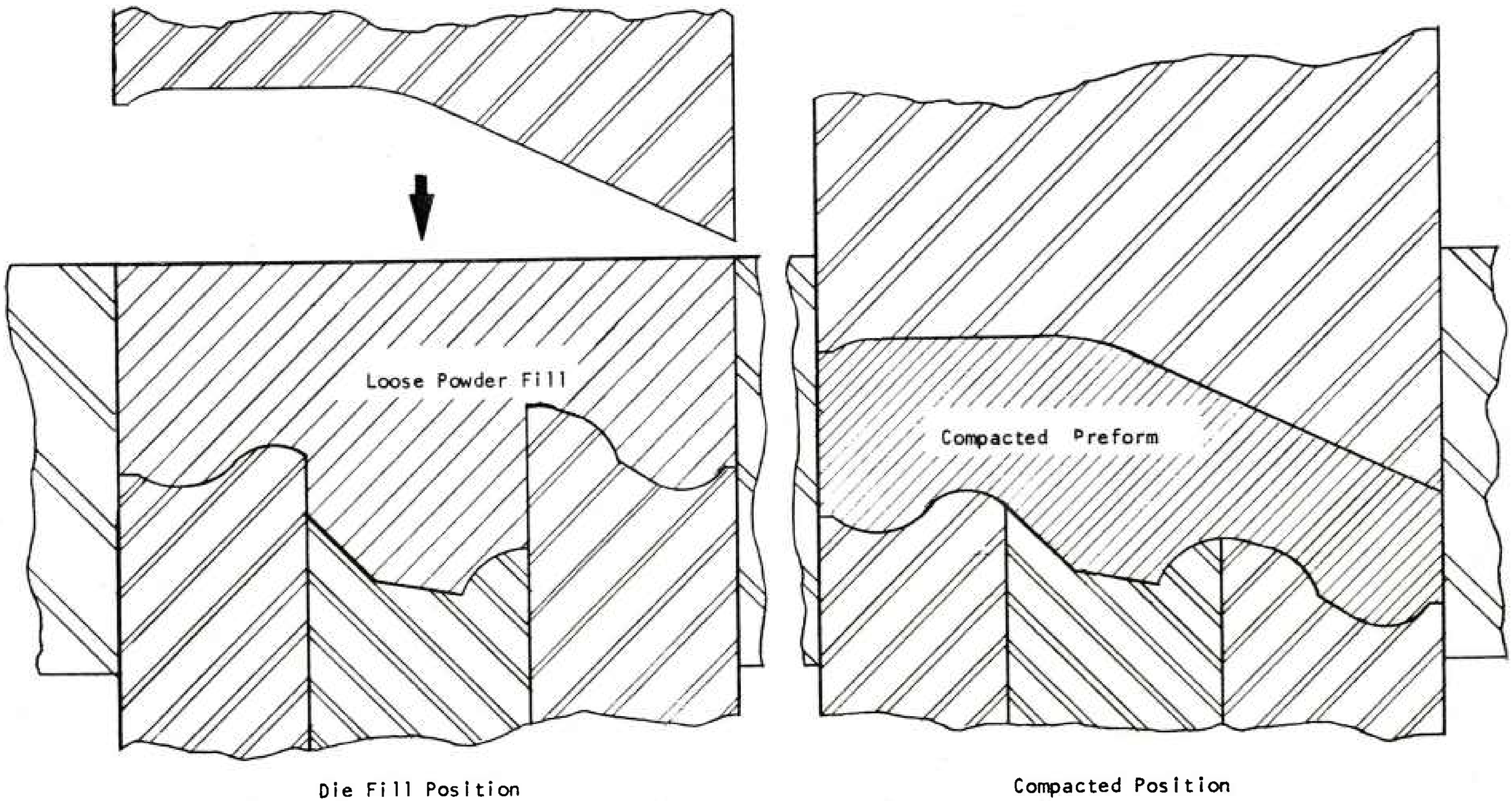


Figure 3. Schematic of Die Pressing Action.

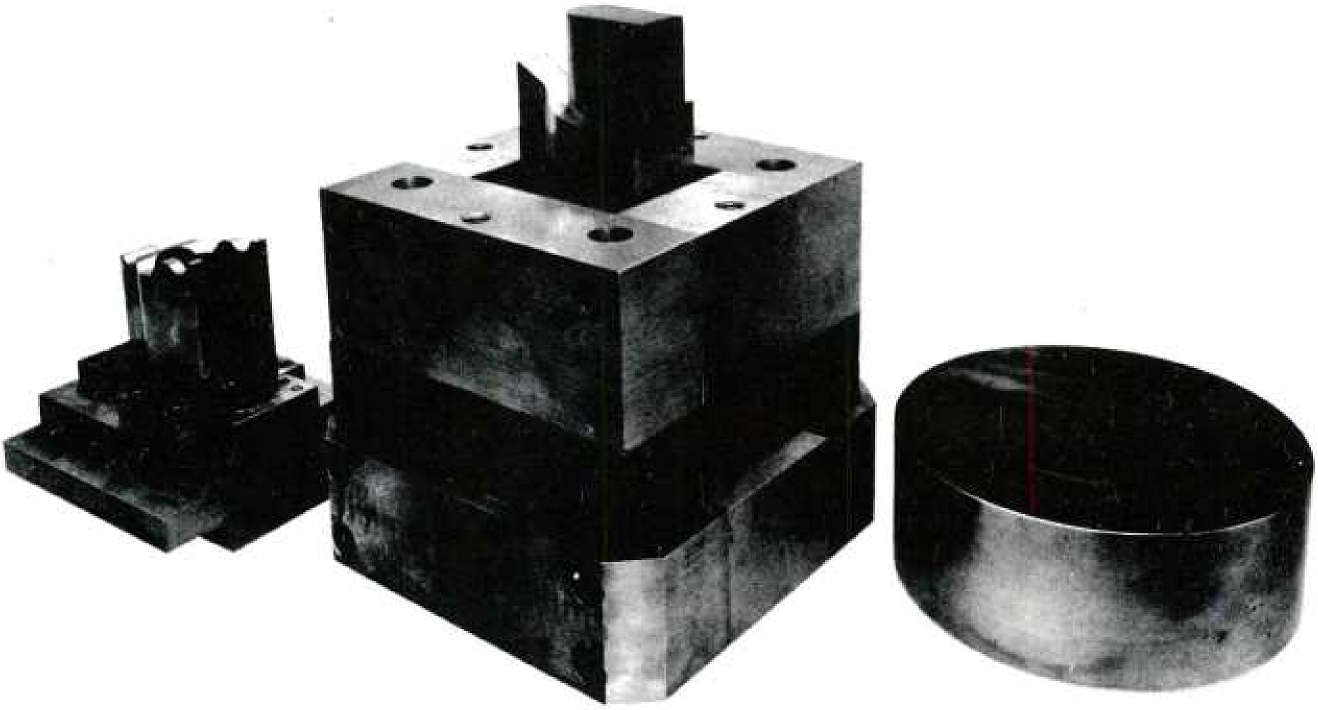


Figure 4. Minimum Deformation Tooling Shown Disassembled Prior to Installation.

1634 C

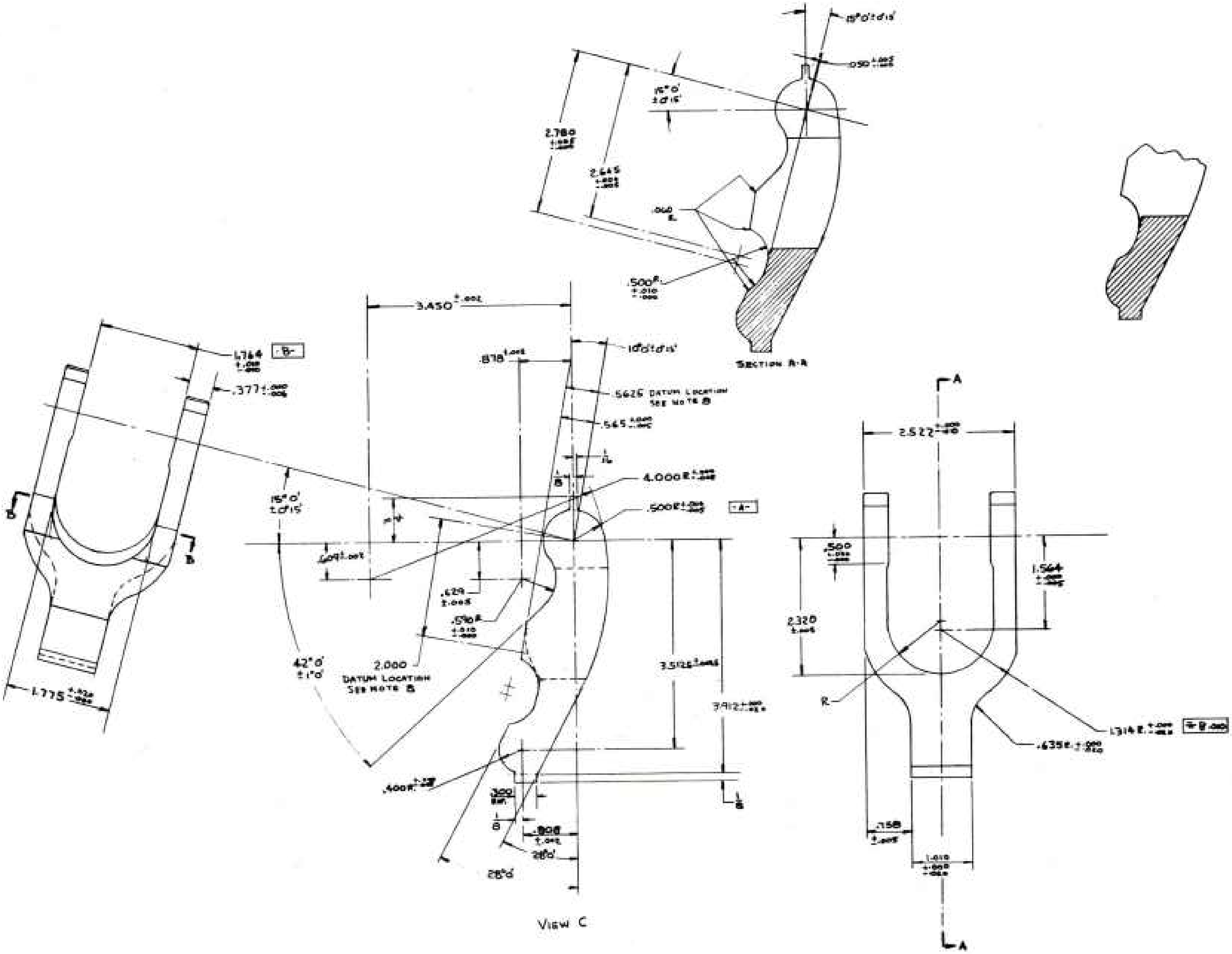


Figure 5. As-Forged Configuration of the Accelerator.

d. Mill the 3.832 inch dimension, the 0.406 inch slot and the 0.125 inch x 45° chamfers.

e. Mill the I.D. radius.

f. Machine the 45° clearance angle (see Section BB, Figure 1 of subject report.

g. Machine the 0.040 inch x 45° chamfer.

h. Barrel finish to remove burrs.

i. Heat treat to R_c 46-51.

j. Chrome plate.

k. Apply protective finish.

Forgings produced during the subject program, however, were to be delivered to RIA in the as-forged condition.

The program was organized into nine tasks, each of which are briefly described as follows:

TASK 1 - Material Procurement

The material, 4600 prealloyed powder, was obtained from the A. O. Smith-Inland Company in a lot size sufficient to complete the program needs. The raw powder was characterized by means of particle size and shape analysis (by SEM), particle metallography including hardness tests and by chemical analysis.

TASK 2 - Adaptation of Tooling

The forging tooling was constructed for use in a hydraulic press and some modifications of the die set were required to adapt the tooling for service in a crank press and a steam drop forging hammer. A die set was designed and built incorporating hydraulic cushions to absorb the excess energy generated by the press or hammer. The die set also included an ejection mechanism to recover the forging and provide the close alignment of punch and die required for successful operation of the tooling. The die set designed for use in a forging hammer was also used for mechanical press forging.

TASK 3 - Preform Fabrication

This task was concerned with compacting and sintering the preforms required for completion of the program. The procedures developed on the previous contract were employed.

TASK 4 - Hydraulic Press Forging

A total of 50 forgings were produced by hydraulic press forging to provide a basis of comparison for the forgings produced by the mechanical press and forging hammer.

TASK 5 - Mechanical Press Forging

Using the die set generated during the Task 2 effort, 50 accelerator forgings were produced on a crank type mechanical forging press.

TASK 6 - Hammer Forging

This task was devoted to evaluating the utility of the steam drop hammer for forging P/M accelerator preforms. As described in Section 3.6, no actual forging was performed in the forging hammer.

TASK 7 - Evaluation

This task was concerned with evaluating all the forgings for density, dimensional accuracy and surface finish on a 100% basis, and chemistry and metallurgical quality on a sampling basis.

TASK 8 - Cost Analysis and Comparison

This task was devoted to a cost analysis based on production lots of 1000, 10,000 and 100,000 pieces. The analysis included capital equipment amortization and costs of modifying existing equipment.

TASK 9 - Survey of Components and Facilities Requirements

Weapons components which could benefit from P/M forging were surveyed and classified in terms of size, shape complexity and property requirements. Wherever feasible, existing facilities were considered for production requirements.

3.0 RESULTS AND DISCUSSION

As outlined in the previous section, the program was designed to investigate the feasibility of P/M forging on existing forge shop equipment of standard design. The accelerator, produced by minimum deformation forging, was selected to demonstrate the process and hydraulic and mechanical forging presses and a steam drop forging hammer were studied and compared.

3.1 TASK 1 - Material Procurement

The material selected for use in the program, a modified 4600 composition, was obtained from the A. O. Smith-Inland Company in sufficient quantity to complete the program. This is a true prealloy manufactured by water atomization of the melt and subsequently treated to reduce oxide content. The powder composition is a modified form of the AMS specification for 4600 wrought material (AMS-6317B). The chief modifications are lower Mn and Si contents and higher Mo addition. The modified composition is better suited to powder metallurgy applications because of the lower Mn and Si content, which form difficult-to-reduce oxides.

The raw powder was characterized by particle size and shape analysis, metallographic inspection, including particle hardness and chemical analysis. Additionally, particle density measurements were performed with the Beckman air pycnometer to determine intraparticle porosity.

The sieve analysis was performed as per ASTM standard designated B-214-56. The analysis made by TRW is compared with the vendor's analysis in Table I. The data are in general agreement and show a normal size distribution which conforms to normal commercial limits.

The particle shape analysis was performed by SEM examination. The basic particle shape which is illustrated in Figure 6, is characteristic of water atomized low alloy steel powders and is derived from a distorted, flattened or elongated sphere. The particle surface is characterized by many small nodules. The nodules increase surface area of the powder and contribute to good green strength by providing mechanical interlocking of the particles during compaction.

Metallographic inspection was performed for cleanliness, homogeneity, hardness and inclusion and void content. The powder was found to be relatively clean and homogeneous with a low level of inclusions and very little internal porosity. Typical particle microstructures are illustrated in Figure 7. The low level of intraparticle porosity was confirmed by a particle density measurements which showed a particle density of 7.78g/cc or less than 1% internal porosity.

The chemical analysis presented in Table 2 compares relatively well with the vendor's analysis, which is included in Table 2, with the possible exception of the Mo analysis. The variation in Mo analyses was not consid-

TABLE 1

4600 PREALLOYED POWDER DATA

Screen Analysis

Retained on Sieve No.	Passing Sieve No.	Vendor Analysis Lot No. 8234 %	TRW Analysis %
100 (149μ)	-	8	8
150 (104μ)	100 (149μ)	20	21
200 (74μ)	150 (104μ)	25	21
250 (61μ)	200 (74μ)	4	9
325 (44μ)	250 (61μ)	20	1
-	325 (44μ)	23	40

Vendor Data

Apparent Density 2.99 g/cc

Flow Rate 24.8 sec/50g

*Green Density 6.51 g/cc

Green Strength 841 PSI

TRW Data

Particle Density 7.78 g/cc

Particle Hardness 188.9 KHN (25g load)

* @ 30 TSI - .75% Zinc Stearate.

Figure 6. Typical Particle Shapes of As-Received 4600 Prealloyed Powder.

100X

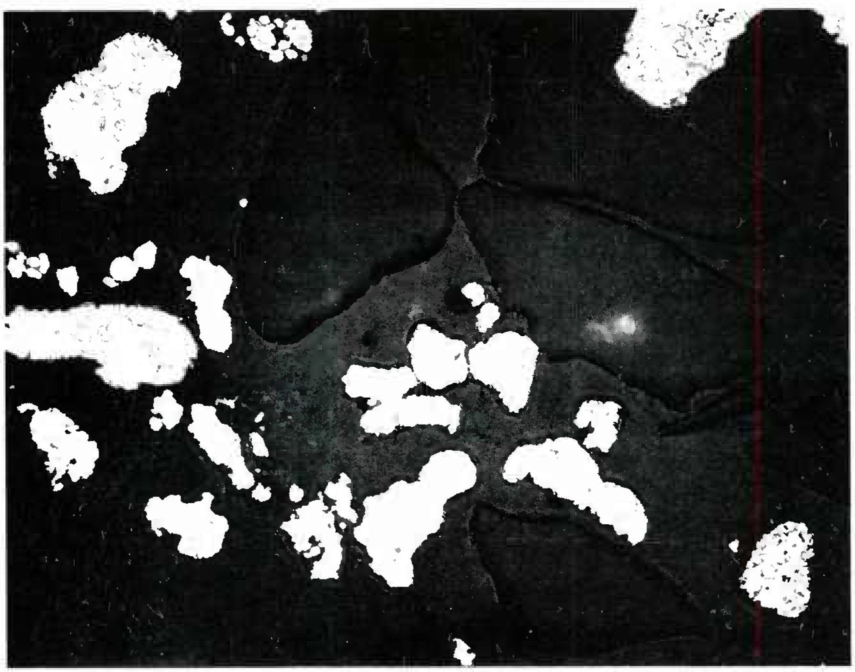


Figure 7. Typical Particle Metallography of As-Received 4600 Prealloyed Powder.

100X

TABLE 2

CHEMICAL ANALYSIS OF 4600 PREALLOYED POWDER

Element	AMS 6317B Specification %	Vendor Analysis %	TRW Analysis %
*C	-	-	-
Ni	1.65 - 2.00	1.60	1.58
Mo	.2 - .3	.50	.26
Mn	.6 - .8	.19	.26
P	.04 Max.	-	-
S	.04 Max.	.023	-
Si	.2 - .35	-	.016
O_2	-	.15	.16

* Carbon added to powder blends to meet AMS Specification for 4640 composition.

ered serious enough to warrant further investigation. The oxygen level of 0.15% (1500 PPM) is typical of water atomized prealloyed powders. This level requires reduction to less than 300 PPM during subsequent processing to meet the requirements of P/M specification MIL-F-45941 and to achieve acceptable impact properties in the forged material.

The results of the material characterization showed that the prealloyed powder is of good quality and is acceptable for use in the program.

3.2 TASK 2 - Adaptation of Tooling

The primary effort of this task was to modify the accelerator forging tooling, previously developed on Contract No. DAAF01-70-C-0656, for service in a mechanical crank-type press located at TRW) and a steam drop forging hammer (located at RIA). An additional effort was to resize the forging die and punches to produce dimensionally accurate forgings.

The tooling for forging the accelerator, illustrated in Figure 4 prior to assembly, is of the three-piece type with a ring-type die and upper and lower punches. The forging is a one-blow operation and is carried out in a completely closed die system with no provision for flash. The design imposes three requirements on the press or forging machine, which are:

1. Control of forging pressure or force exerted on the tooling.
2. Accurate alignment between the upper punch and the die.
3. An ejection mechanism for recovery of the forging from the die.

The accelerator forging tooling was designed for use in a hydraulic press which meets all three requirements without modifications. Mechanical presses generally can meet the alignment requirement without auxiliary tooling and can be provided with an ejection cylinder without extensive modifications.

Forging hammers do not meet any of the three requirements and these capabilities must be incorporated into the tooling setup or die set. Hammers, shown schematically in Figure 8, have no provisions for an ejection system, nor can the machine be modified to provide one. The hammer must be selected with sufficient daylight (distance between ram and anvil) to provide space for an ejection cylinder in the die set.

Press capacity is another consideration. The minimum deformation process is carried out at 40 TSI and required 160 tons force to produce sound accelerator forgings on a hydraulic press. Mechanical press capacity should present no problem since the presses available are in the 500 to 700 ton range. The principal requirement with the mechanical press application (Task 5) is to prevent overloading of the tooling.

The smallest forging hammer available with suitable space for tooling is a 1000-pound Chambersburg steam hammer located at RIA. This hammer has a nominal maximum energy output of 11,000 ft-lbs. Accelerator forging in the

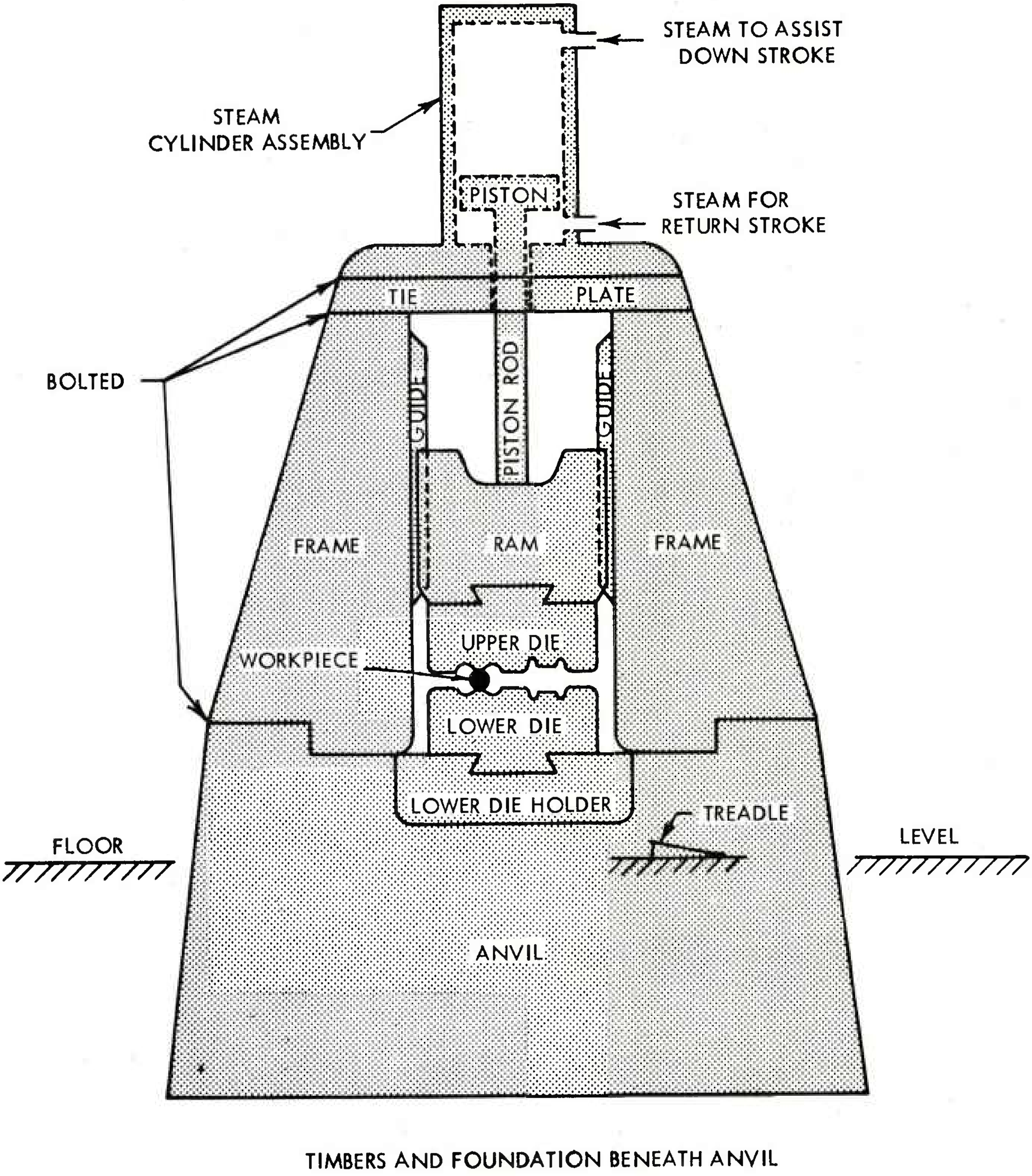


Figure 8. Simplified Illustration of Steam Drop Hammer Construction Showing Major Components. Steam Generation Facilities and Valving For Throttling (Treadle Controlled), Return, and Exhaust Not Shown. Multiple Impression Dies, As Illustrated, Will Not Be Used For P/M Forging.

hydraulic press required 160 tons force with 0.300 inch deformation of the preform. The energy requirement, force x displacement, is 160 tons x 0.3 inches or 8000 ft-lbs as a maximum assuming that the maximum force was required for the full displacement. A more realistic approximation would be 1/2 this maximum or 4000 ft-lbs. Additionally, because of the much higher speed of the forging hammer and consequently less chilling of the preform, lower forging forces are anticipated. Therefore, it is estimated that 3000 to 4000 ft-lbs should be adequate for forging accelerators.

The die set design for service in the forging hammer is shown in Figures 9, 10 and 11.

The hydraulic cushions are incorporated into the sow block. The two 10-inch diameter cylinders operating in tandem at 2000 psi line pressure provide a maximum of 160 tons cushion. The cylinders are serviced by two 1-1/8 inch diameter hydraulic lines contained in the base plate and ported directly under the pistons. The hydraulic circuit, shown schematically in Figure 11 includes two accumulators mounted one on either end of the sow block for fast response.

The die support block (Figure 10) is mounted directly on the sow block and holds the die in a fixed position. The core rod, which forms the inner surface of the forging, is mounted on a plate which in turn is mounted on the hydraulic cushions. The lower punch is mounted on an ejector plate which is also supported by the hydraulic cushions. Ejection of the forgings is performed by two hydraulic cylinders mounted at opposite ends of the ejector plate. Alignment is provided by four interlocks machined into the die holder and upper punch holder. The interlocks are also designed to "kiss" at 1/16 inch deflection of the hydraulic cushions to absorb excess forces generated during forging.

The shut height of the proposed die set is 20 inches, of which 5-1/2 inches are built into the sow block. The nominal working space in the 1000 pound Chambersburg hammer is 14-1/2 inches from the bottom of the sow block to the face of the ram at the bottom of the working stroke. The height of the die set will then subtract from the working stroke of the hammer (20"-14-1/2 = 5-1/2").

These dimensions provide a minimum of 6 inches clearance between the face of the die and the lower surface of the upper punch at the bottom of the ram oscillation. This space provides clearance for loading the preform into the die and retrieving the forging after the cycle is completed.

The partially assembled die set is shown in Figure 12 with the ejection cylinders in place at either end and with the die holder block and die removed. The assembly is shown with the ejection cylinders fully extended. The die holder is the large block at the upper left of Figure 12, and the upper punch holder is at the upper right. Also visible in the photograph is the thermal insulation provided between the hydraulic cushions and the base plate, the ejection cylinders and the die holder.

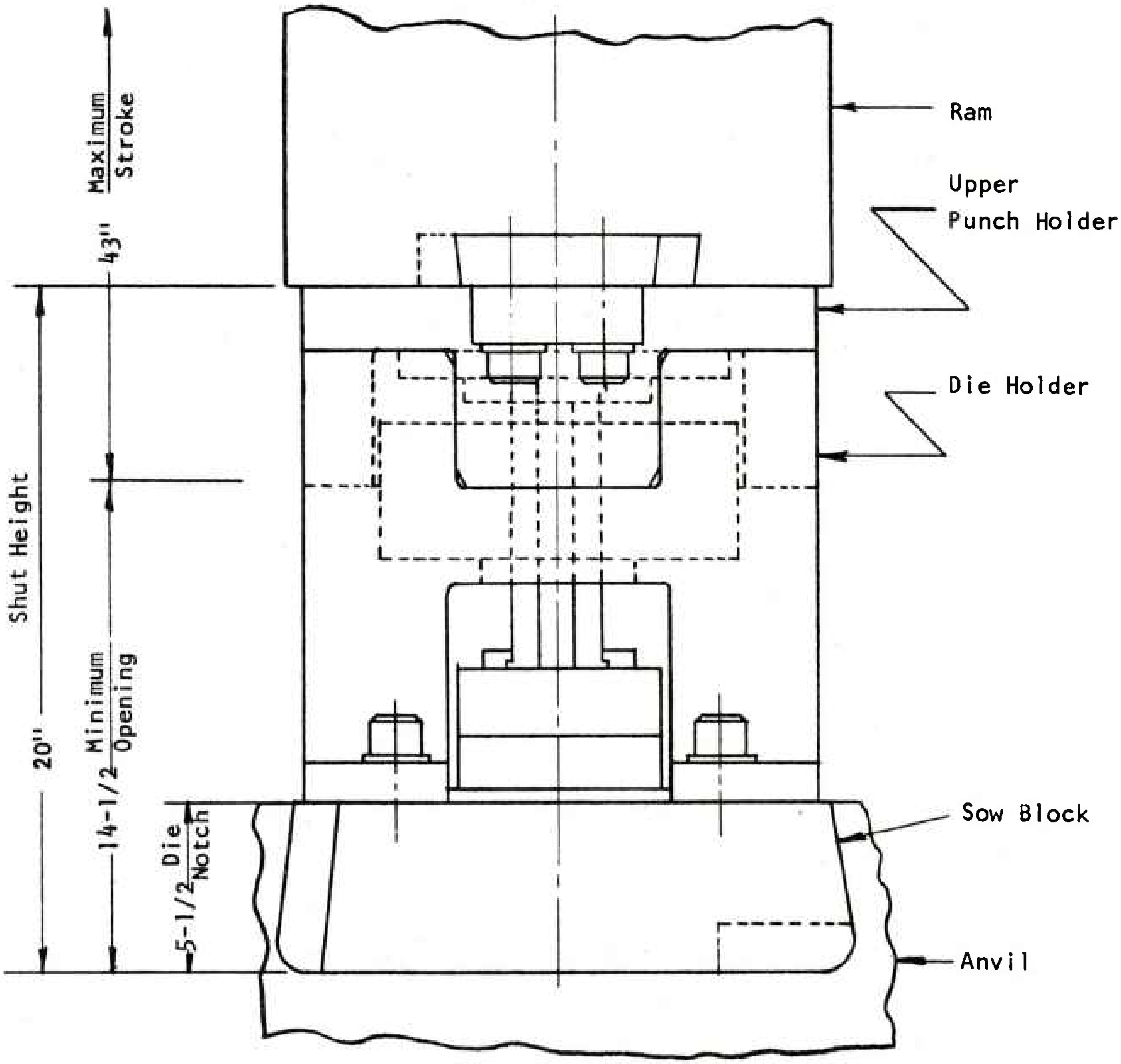


Figure 9. Front View of Die Setup for P/M Forging Accelerators In 1000 Lb. Chambersburg Steam Drop Hammer. Shown With Ejection Cylinders Removed.

6803-C

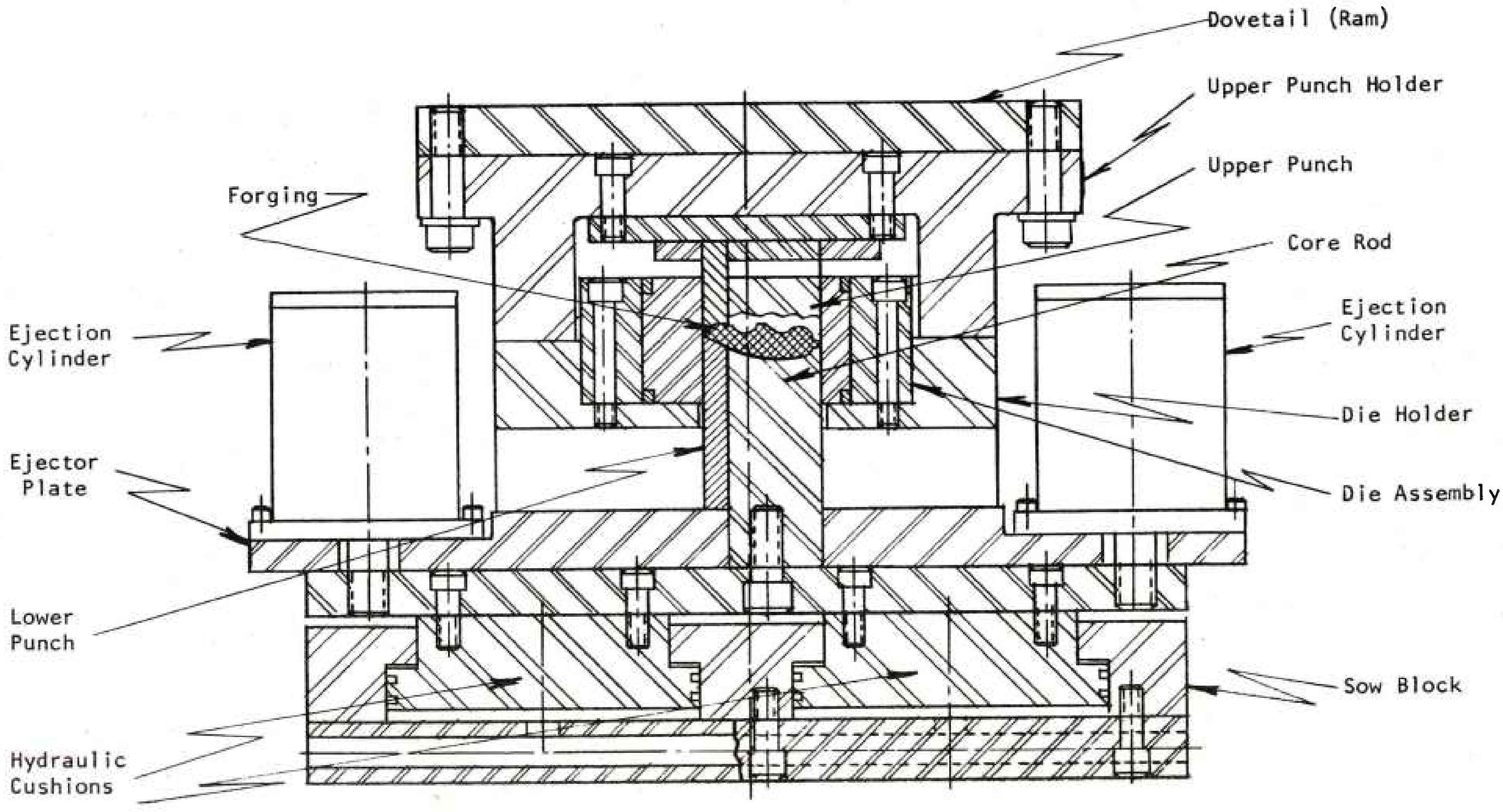


Figure 10. Longitudinal Section View of Die Set for P/M Forging Accelerators In a 1000 lb. Chambersburg Steam Drop Hammer.

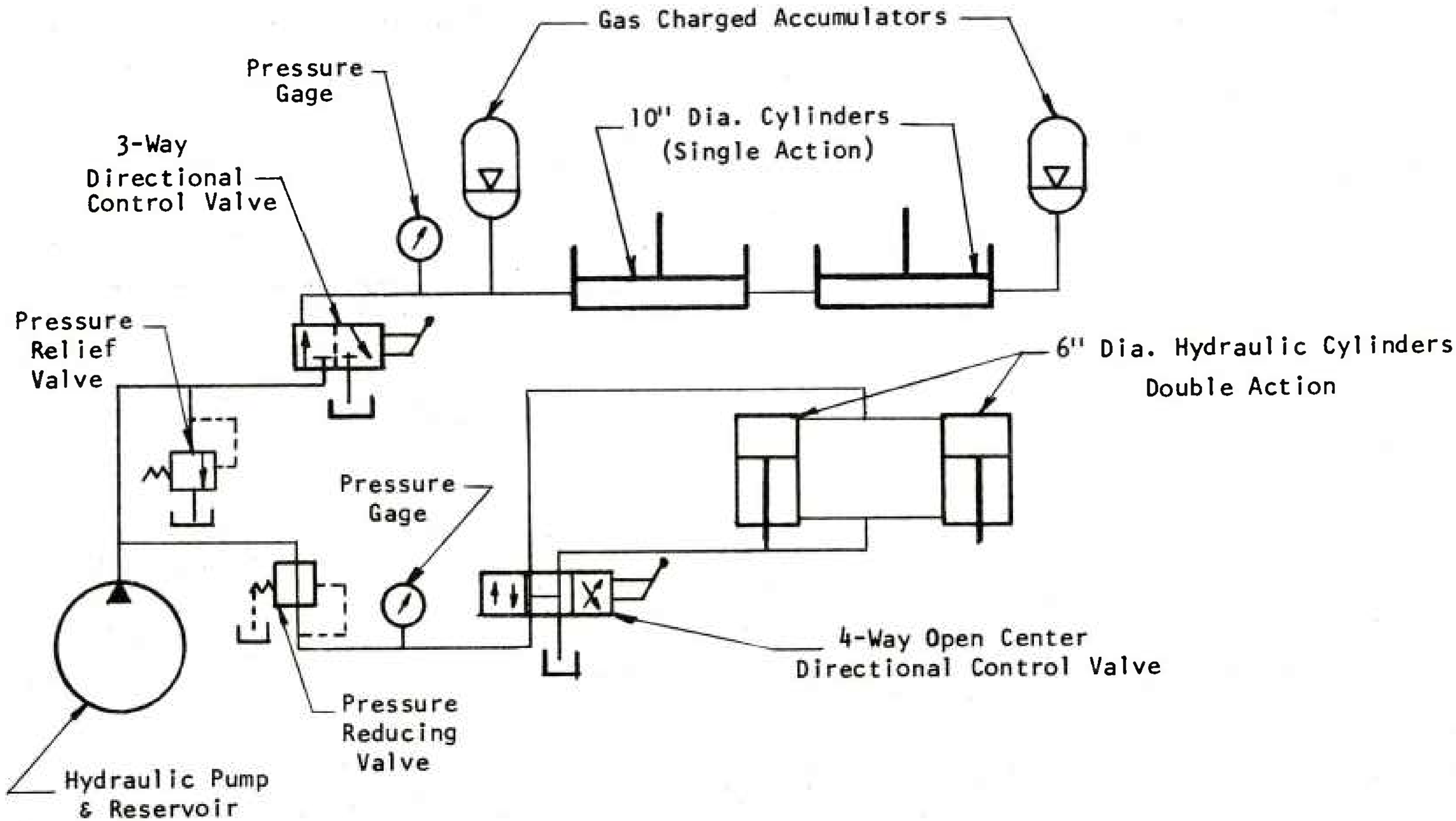


Figure 11. Schematic of Hydraulic Pressure Control Circuit for Hammer Forging Die Setup.

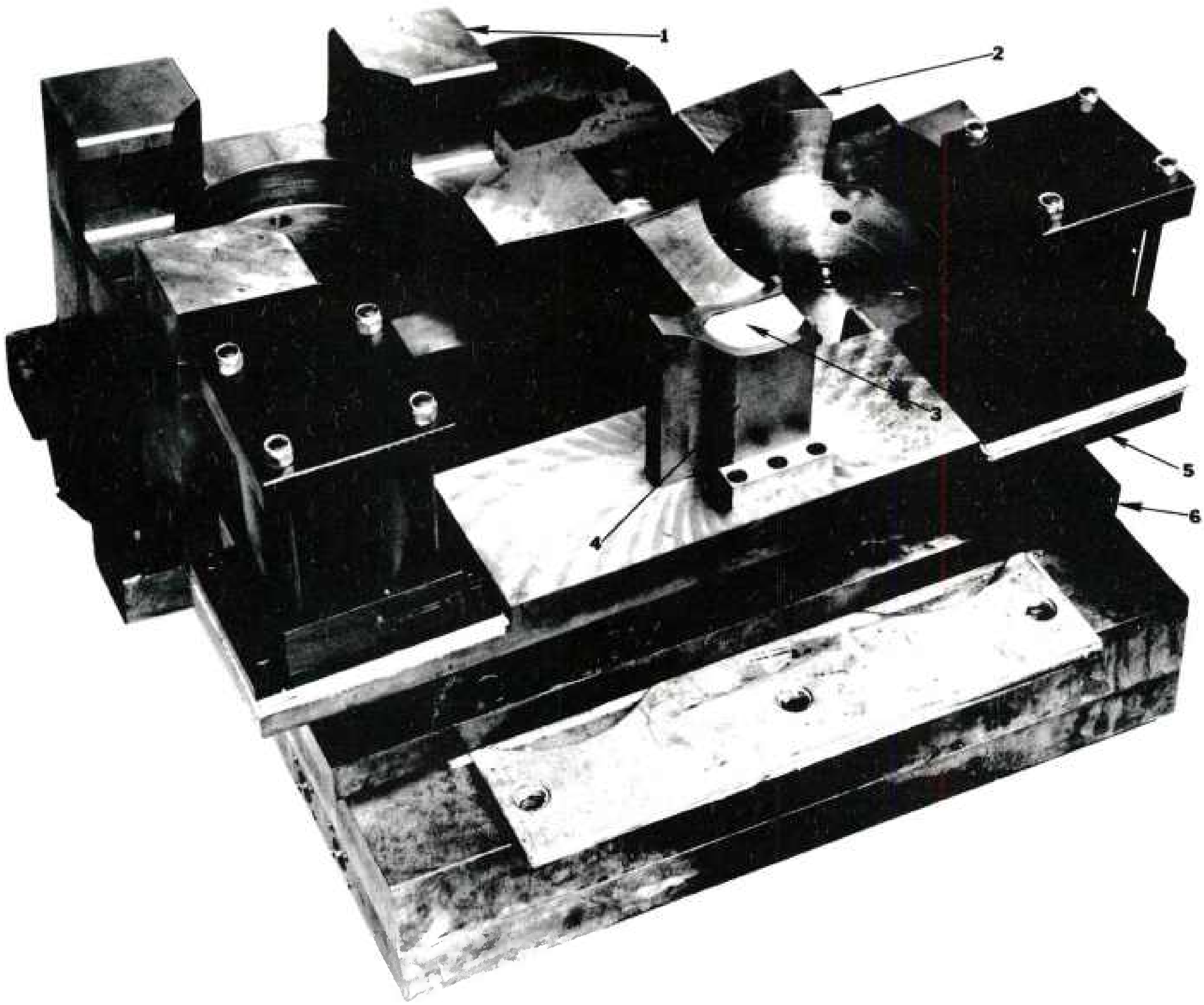


Figure 12. Partially Assembled Hammer Forging Die Set Showing:
(1) Die Holder Block, (2) Upper Punch Holder Block, (3) Core Rod,
(4) Lower Punch, (5) Ejector Plate, and (6) Base Plate.

7239-C

The thermal insulation is the load bearing type and consists of alternate layers of 0.050 inch 310 stainless steel and 1/16 inch thick asbestos cloth. The thermal insulation was provided to prevent the overheating of the hydraulic oil in the system.

The fully assembled die set is presented in Figure 13 prior to installation in the press for tryout. The initial tryout was performed in a hydraulic press using the installation as illustrated in Figure 14. The hydraulic pumping system servicing the die set cushions and ejection cylinders is also visible. The hydraulic system also incorporates two accumulators, one of which is visible at the front of the press, to absorb the shock loading generated by the press or hammer forging actions.

3.3 TASK 3 - Preform Fabrication

This task is concerned with establishing the preform weight tolerances and material distribution to accommodate the resized forging tooling. The preform design and preform compacting tooling were developed during work on Contract No. DAAF01-70-C-0656.

The relatively thin sections and large surface area of the accelerator are not conducive to metal flow during forging. Therefore, it is a requirement of the preform to provide for uniform consolidation of all sections during forging with a minimum of metal flow.

The preform tooling required minor modifications to improve weight control and precision. The compacting tooling, shown in Figure 15, is provided with multiple level lower punches with adjustments to provide control over the volume of material in various sections of the preforms. The lower punch segments are positioned by small air powered cylinders incorporated in the die set. These cylinders were converted to hydraulic action to provide for more positive location.

Preforms were optimized by measuring sections of the forging to determine the density of each segment. Adjustments were then made on compacting tooling until a preform was produced which could be forged with a density of 99.5% minimum in all sections. The idealized weight and weight tolerances were then determined by weight and dimensional inspection of a number of forgings.

A quantity of preforms sufficient to complete the requirements of Task 4, hydraulic press forging, was processed after preform optimization. Compacted preforms were sintered at 2200°F for 60 minutes in a hydrogen atmosphere. Methane additions (0.5%) were employed to prevent loss of carbon during sintering. Typical sintered preforms are presentedin Figure 16.

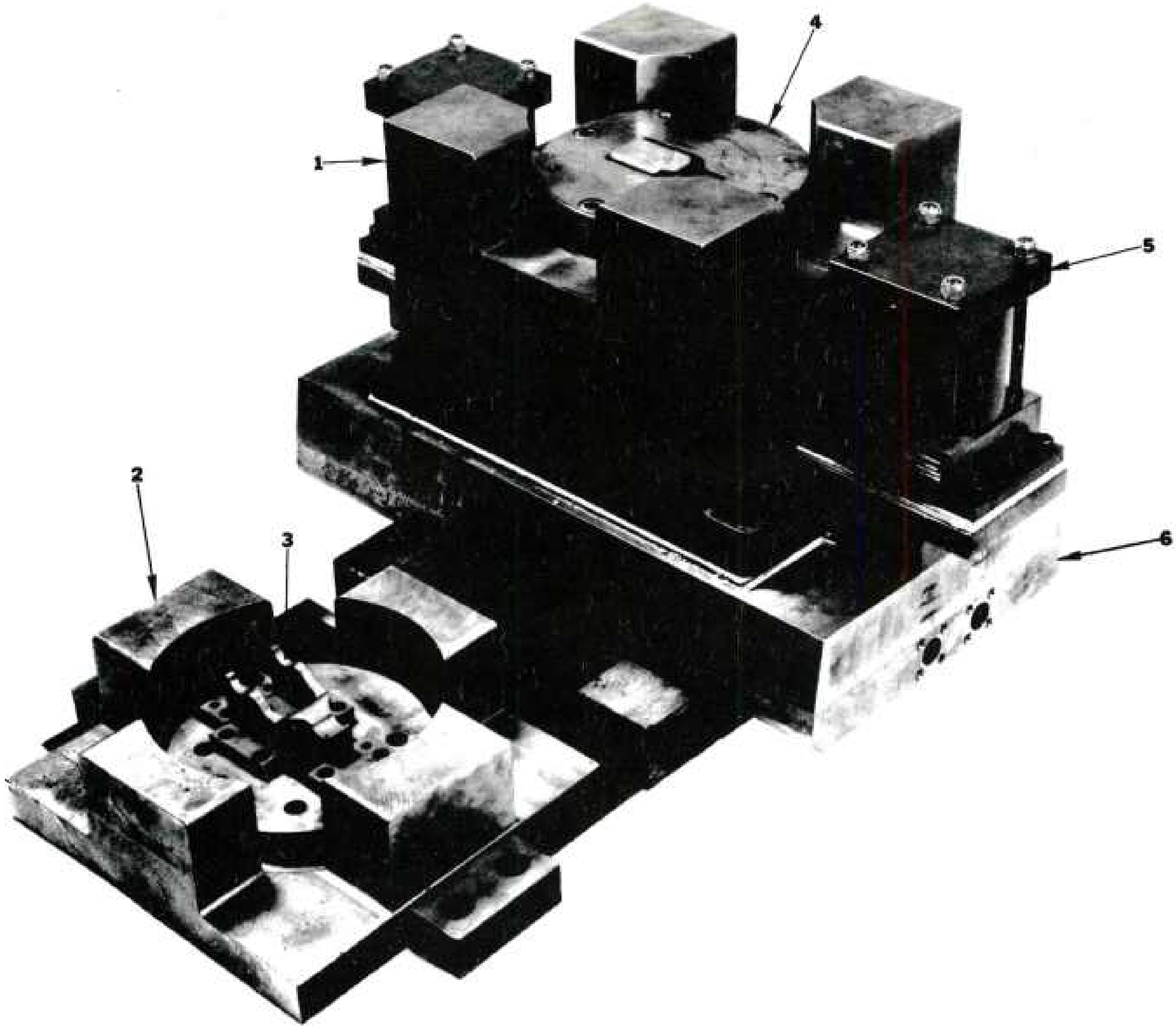


Figure 13. Assembly of Hammer Forging Die Set Showing:
(1) Die Holder Block, (2) Upper Punch Holder Block, (3) Upper Punch,
(4) Forging Die, (5) Ejection Cylinder, and (6) Sow Block.

7240-C

Figure 14. Hammer Forging Die Set Installed in a Hydraulic Press for Initial Tryout.

7243-C

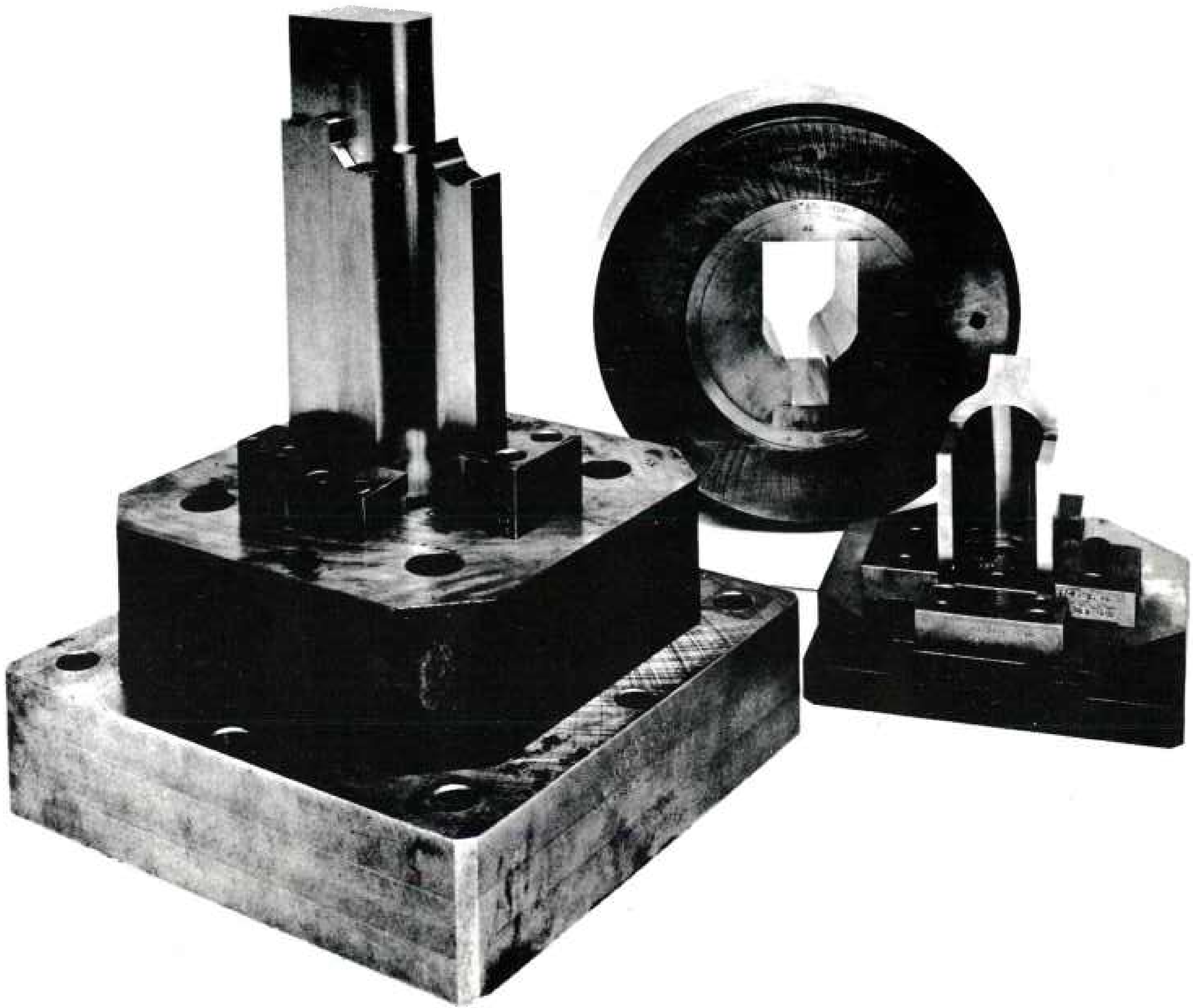


Figure 15. Compacting Tooling for the Accelerator Preform, Shown Prior to Assembly.

1633 C

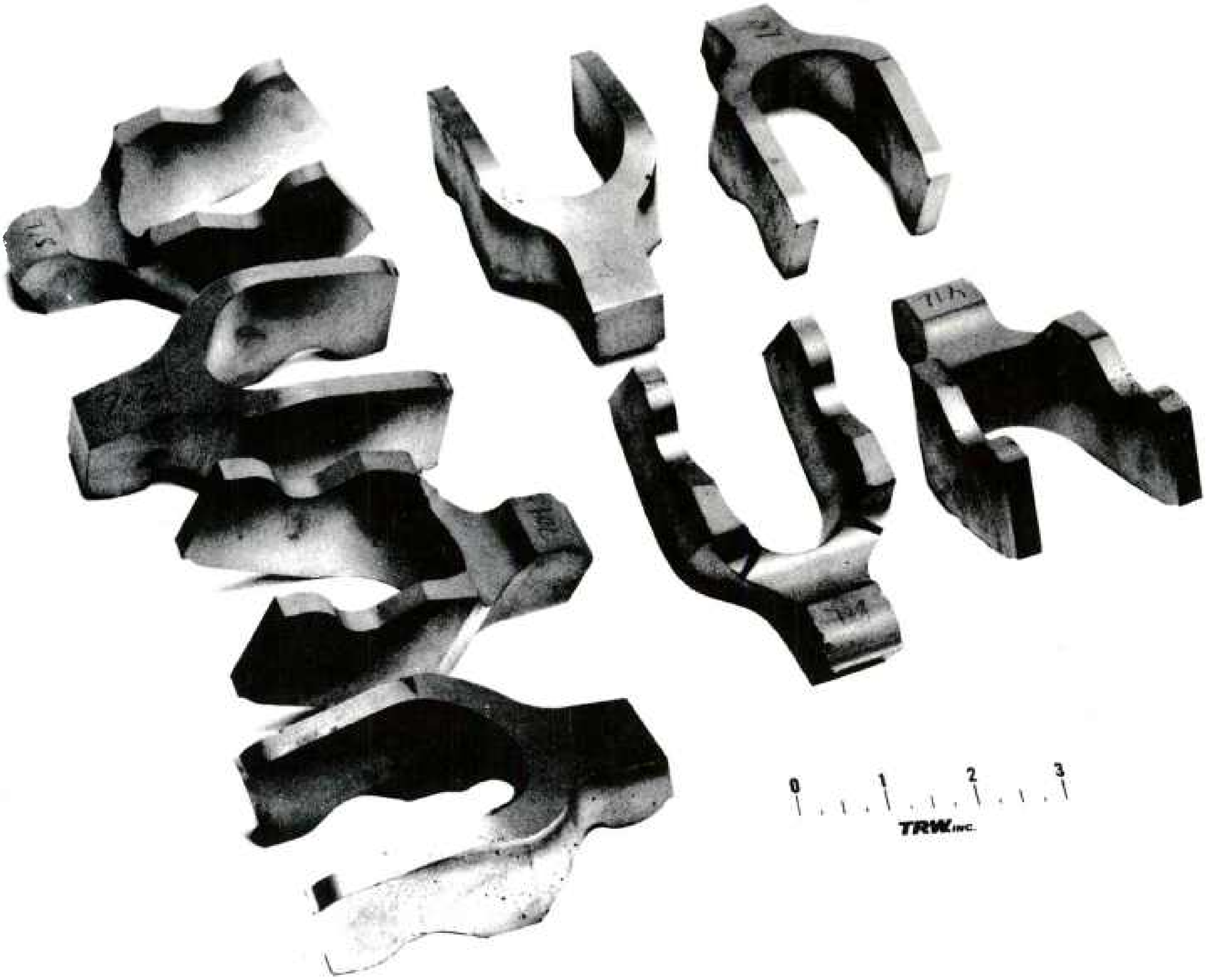


Figure 16. As-Sintered Preforms Used in P/M Forging of Accelerators.

7241-C

3.4 TASK 4 - Hydraulic Press Forging

This task was concerned with producing 50 accelerator forgings on a hydraulic press in order to establish baseline data for comparison with the mechanical press and hammer forgings.

The forging operation was performed in a Lake Erie hydraulic press having a nominal rating of 150 tons and a ram velocity of 90 inches per minute. Forging was carried out at 40 TSI which required a press load of 160 tons, a slight overload of the press capacity. Sintered preforms were heated to 2200°F in a hydrogen atmosphere with a methane addition to prevent decarburization. No preform coating was used. Forging dies were heated electrically to 450°F and a graphite-water lubricant was sprayed into the die cavity. Transfer time of preform from the furnace to the die and the onset of forging pressure was held to 3 seconds or less. Typical as-forged accelerators are shown in Figure 17.

3.5 TASK 5 - Mechanical Press Forging

This task is concerned with producing 50 accelerator forgings in a mechanical press using the same tooling (die and punches), as were used for hydraulic press forgings. The action of the mechanical crank press required some modifications in the die set to permit forging of the accelerators. A typical mechanical press extracts inertial energy from a continuously rotating flywheel by means of air-operated clutch and brake assemblies which connect the flywheel to the crankshaft through one crankshaft revolution. This is translated to one cycle of vertical reciprocating motion of the ram by the pitman assembly with assistance of the ram guides. The maximum downward force of the ram is generally expressed in tons.

Several features of this ram cycle are apparent. First, the stroke is fixed as the diameter of the arc circumscribed by the eccentric (crankpin axis) of the crankshaft. Second, the ram velocity is a function of the ram position; changing from zero at "top dead center" of the crankpin, to maximum linear velocity near 90° of crankshaft arc (at 90° with the scotch-yoke design), and again to zero at 180° of arc (at maximum die closure) when the crankpin is in "bottom dead center" position. Third, the force available is also a function of the ram position and theoretically, by mechanical advantage, is in inverse proportion to the ram velocity. Thus, at the "bottom dead center" position, an infinite force would be generated if it were not for tensile deflections of the frame, bending deflections of the crankshaft, etc. Further, the force available higher in the stroke is significantly less than when dies are virtually closed. Fourth, since the stroke is fixed, the force developed is a function of the resistance which the frame, crankshaft, and all other members in the "force circuit" afford to deflection.

Because of the fixed stroke and the design of the accelerator forging tooling, which has no provisions for flash, the die set must prevent dangerous overloading of the tooling due to oversize preforms. The die set constructed for use in the hammer forging trials was designed such that it could be used for the mechanical press forging effort.

Figure 17. As-Forged Accelerators Produced from Sintered P/M Preforms.

7242-C

The mechanical press forging task was carried out using a crank press with a 16-inch stroke and a variable speed drive with a range of 15 to 30 strokes per minute. The press has a nominal rated capacity of 500 tons which was more than ample for forging accelerators.

The crank press provided a forging speed between that of the hydraulic press and the forging hammer. Calculation of ram speed at 0.500 inches before bottom dead center (BDC) when the punch makes initial contact with the preform indicated that the crank press had a speed range of 130 to 265 inches per minute. THe hydraulic press had a pressing speed of 94 inches per minute and the drop hammer - 10,000 to 15,000 inches per minute.

The installation in the crank press is illustrated in Figure 18. The forging operation was performed with the same preform heating and process parameters as were used for hydraulic press forging except that a gas torch was used to preheat the dies. A gas torch was used to heat the die because the electrical heating system was not available at the mechanical press.

3.6 TASK 7 - Quality Evaluation and Comparison of Forgings

This task is concerned with establishing the quality level of the forgings produced on the different types of forging equipment. Forged components were inspected on a 100% basis for those dimensions which were established by the punches across the parting line. Die established dimensions were also inspected on the same basis so that reproducibility of all three types of forgings could be compared. Metallurgical quality of forgings was determined on a sampling basis using 2 forgings which were representative of the first and last part produced. Forgings were evaluated in conformance to the requirements of MIL-F-45961 except that no mechanical property measurements were made because a satisfactory test specimen could not be obtained from the forged accelerators.

The quality evaluation of the forged accelerators was performed by means of dimensional, metallurgical and visual inspection. Dimensional inspection was performed on a 100% basis on the dimensions indicated in Figure 19. These include surfaces generated by the forging die as well as across-the-forging plane dimensions which are controlled primarily by weight control of the preforms. Dimensions established by punch contours, which can be expected to be fairly constant, were measured by layout inspection of the first and last forgings produced. Metallurgical quality was assessed by metallographic inspection and chemical analysis of representative forgings.

The mean and standard deviations calculated from data for accelerators forged on both types of presses are tabulated in Table 3. The data include the forged weights, dimensions measured across the forging plane and a number of dimensions established by the die. The raw data from which the mean and standard deviations were calculated are presented in the Appendix.

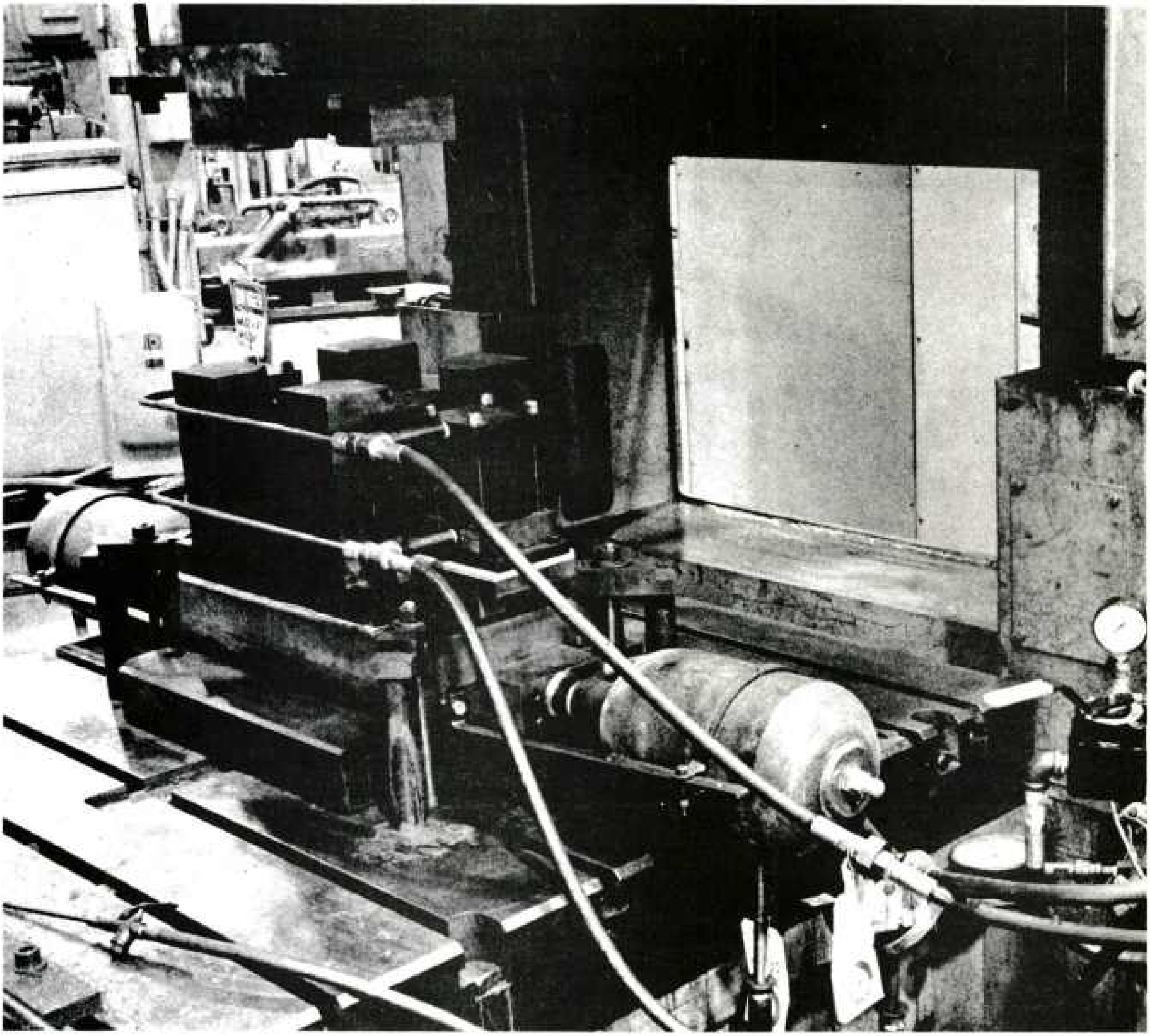


Figure 18. Die Set Installation In a Mechanical Crank Type Press.

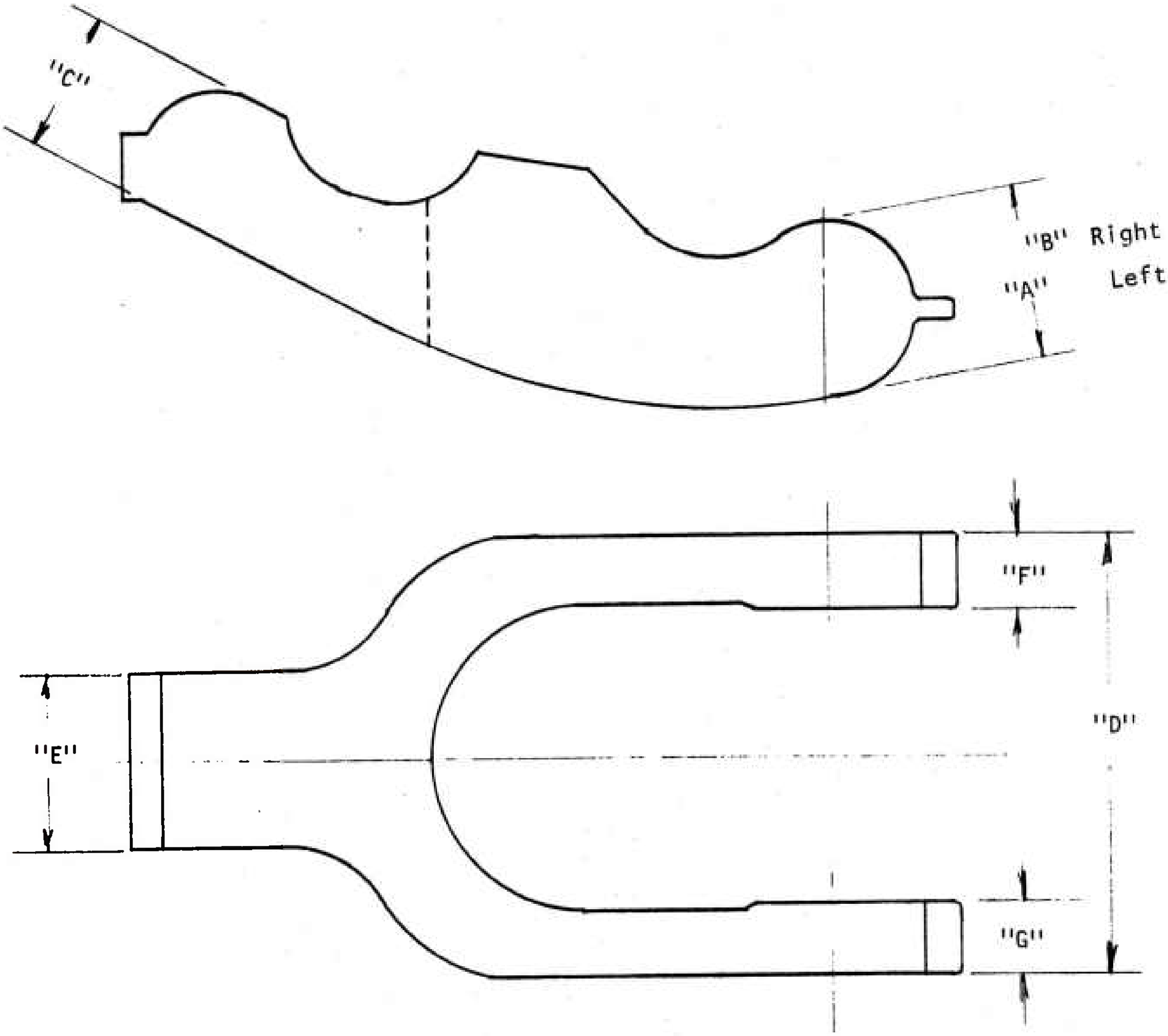


Figure 19. Dimensions Recorded on Forged Accelerators.

TABLE 3

COMPARISON OF DIMENSIONAL DATA

Dimension or Weight	Hydraulic Press Mean	Hydraulic Press σ Std. Dev.	Crank Press Mean	Crank Press σ Std. Dev.
Weight/Gms	476.5	3.66	471.3	3.81
A. L(1 in) $\left(\begin{smallmatrix}+.000\\-.010\end{smallmatrix}\right)$	.997	.006	1.002	.005
B. R(1 in) $\left(\begin{smallmatrix}+.000\\-.010\end{smallmatrix}\right)$	.997	.006	1.004	.004
C -	.697	.007	.694	.004
D. 2.522 $\left(\begin{smallmatrix}+.000\\-.010\end{smallmatrix}\right)$	2.520	.007	2.519	.003
E. 1.000 (±.010)	1.002	.003	.996	.001
F. .377 L $\left(\begin{smallmatrix}+.000\\-.005\end{smallmatrix}\right)$	.374	.001	.372	.001
G. .377 R $\left(\begin{smallmatrix}+.000\\-.005\end{smallmatrix}\right)$	.377	.001	.372	.001

Items A, B and C are measured across the forging plane.

Items D. E. F and G are dimensions established by the die.

Dimensions across the forging plane are established by the upper and lower punches, and all other conditions being equal vary as the preform weight varies. Factors which influence the forged dimensions, in addition to preform weight, are temperatures (die and preform), dwell time (the length of time the forging is held at pressure) and forging pressures. Dwell time variations cause dimensional variations because the forging operation could be performed at varying temperatures due to preform heat loss to the die walls. Some of these variables can be minimized, a timer can be incorporated to minimize dwell time variations, for instance. Hydraulic presses however are controlled by a system of electrically operated valves and hydraulic pressure modulating devices. Such a system has a much larger potential for operational variables such as minor variations in pressure or dwell time than the more straightforward operation of a crank press. The variables can be minimized in a production system, but it seems a reasonable conclusion that a crank press will have less variables than a hydraulic press.

This rationale is supported by the dimensional data presented in Table 3. The standard deviations for dimensions measured across the forging plane are larger for the hydraulic press forgings than the corresponding dimensions measured on the mechanical press forgings. The mechanical press is more reproducible despite the fact that the standard deviation of the preform weights used for mechanical press forgings was larger than the standard deviation of the preform weight used for the hydraulic press forgings. The die established dimensions also show a smaller deviation for the mechanical press forgings as compared to the hydraulic press forgings. These data indicate a decided preference for mechanical presses for P/M forging small precision components.

The dimensional data presented in Table 3 is useful in comparing the relative precision of the hydraulic and mechanical press outputs. These data are not applicable to the determination of the dimensional limits of the process when the process is carried out under production conditions. However, there were no indications that the accelerators could not be P/M forged to the dimensions required by the part drawing with an acceptable yield.

After consideration of the dimensional data of Table 3, it was concluded that the accuracy required for ordnance components such as the accelerator would not be obtained from the steam drop hammer forgings because of the inherent variations in stroke length and force of the hammer blow. The ability to vary the force of the hammer blow which is one of the advantages of the forging hammer for conventional forging is a distinct disadvantage in P/M forgings. The limited advantages of lower capitol investment and the availability of the steam drop hammer equipment in the forge shop at Rock Island Arsenal does not appear to offset the inherent disadvantages associated with this type of forging equipment. Because of this disadvantage of apparently not being able to hold dimensional tolerances and complications with remachining the die sow and dovetail keys, it was decided that the steam drop hammer forging task would not be performed. Other types of equipment such as air operated programmable drop hammers and gravity drop hammers were not available in the forge shop and were not investigated.

The applicability of the steam drop forging hammer to the production of net or near-net P/M forgings is limited to components with larger dimensional tolerances than the accelerator. The classification would include larger components (compared to the accelerator) possibly with draft angles.

The hammer forgings would require more machining operations to meet part tolerances than comparable parts produced in a mechanical or hydraulic press. The cost benefits of the P/M hammer forging process would be derived from high material utilization, the ability to produce one-blow forgings and the increased size capability of the hammer when used for P/M forging. P/M preforms can be forged with little or no flash, hence available press energy is employed in useful forging and is not expended on the generation of flash.

A primary nondestructive test evaluation is the weight-thickness relationship which was performed on a 100% basis. The thickness is defined as the dimension established by the two forging punches across the forging plane. This relationship establishes the density of the forgings on a comparitive basis and identifies forgings which are suspected of having deviated from the normal processing sequence.

The weight-thickness of both types of forgings are plotted in Figure 20. The plots indicate different acceptability limits (i.e., meeting minimum density specified) for hydraulic and mechanical press forgings produced from the same die. The mechanical press forgings are somewhat smaller in die established dimensions and hence somewhat thicker across the forge plane. The acceptability limits were determined by density measurements of the as-forged accelerators.

The high density of the forgings was confirmed by metallographic examination. The microstructure, as shown by Figure 21, was generally free from porosity and inclusions. Homogeneity was also found to be acceptable. Representative microstructures of the oil quenched and tempered (R_c30) forged material are presented in Figure 22.

No differences in microstructure were noted between the hydraulic and mechanical press forgings.

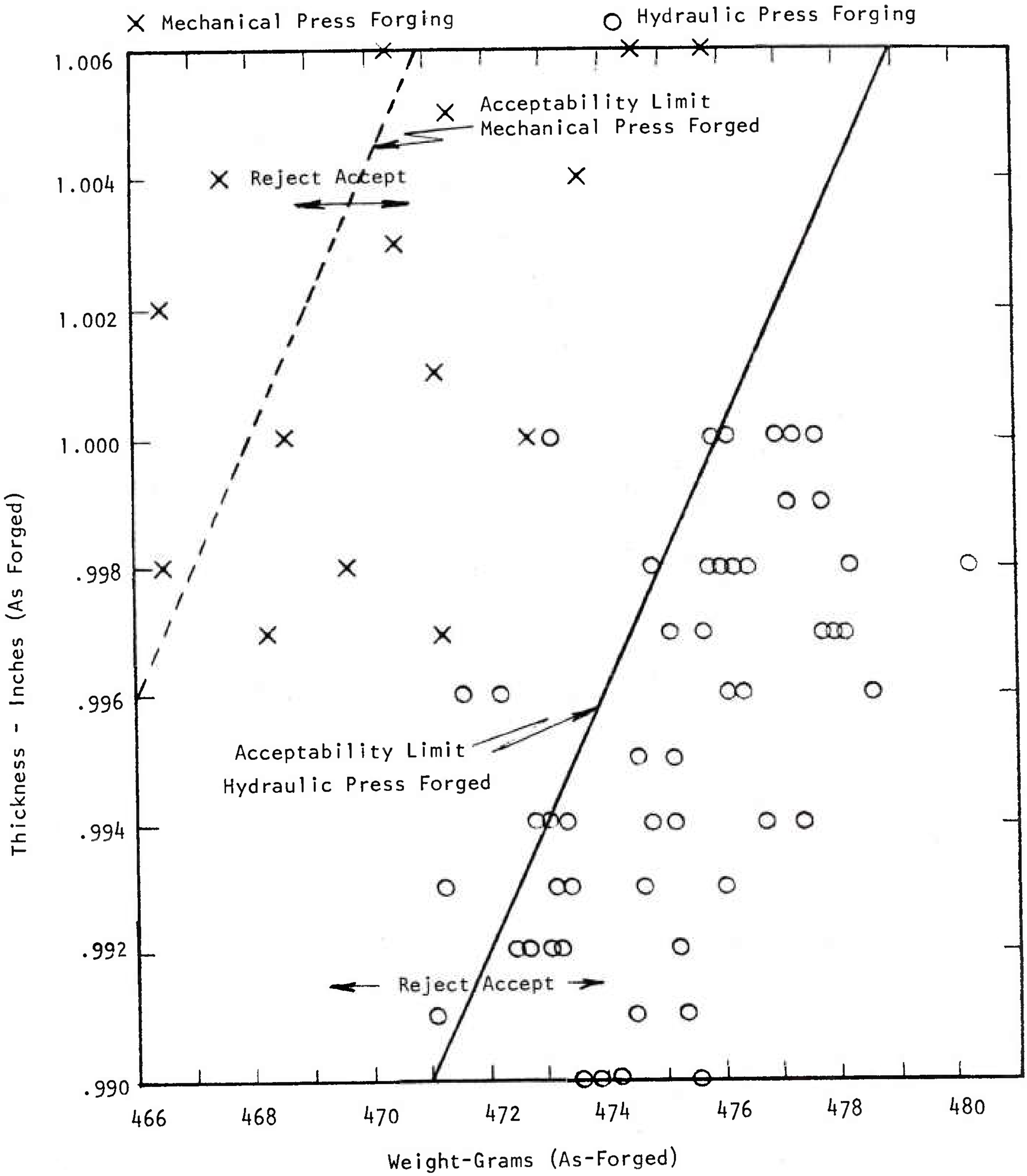
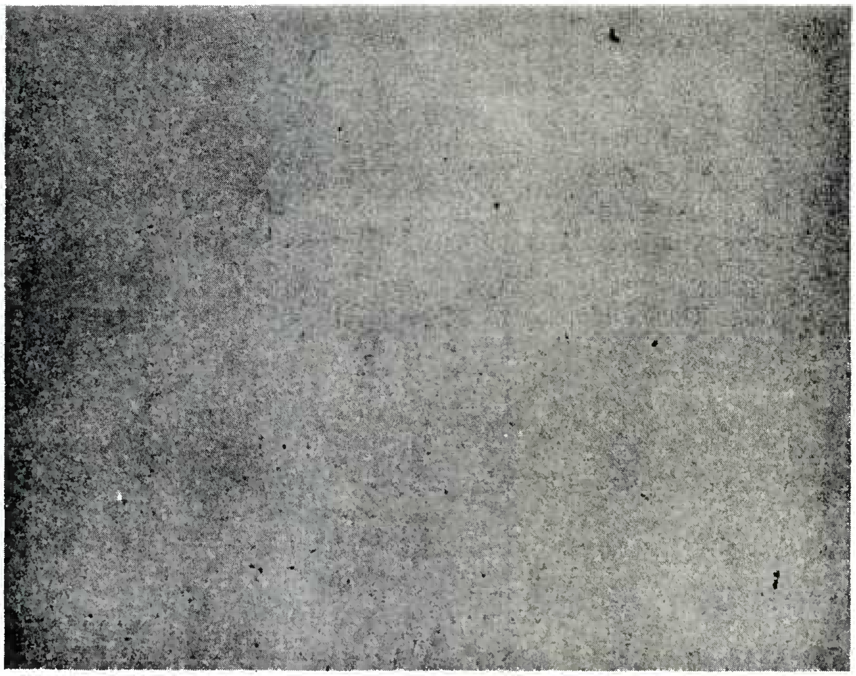
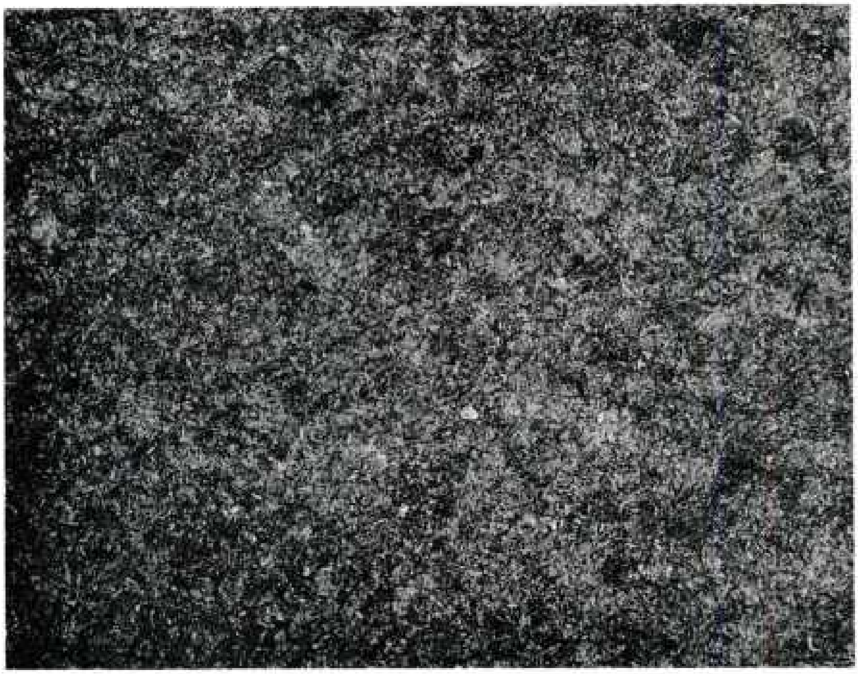


Figure 20. Weight (Forged) vs. Thickness Plot of Accelerators Forged on A Hydraulic Press and A Mechanical Crank Type Press.

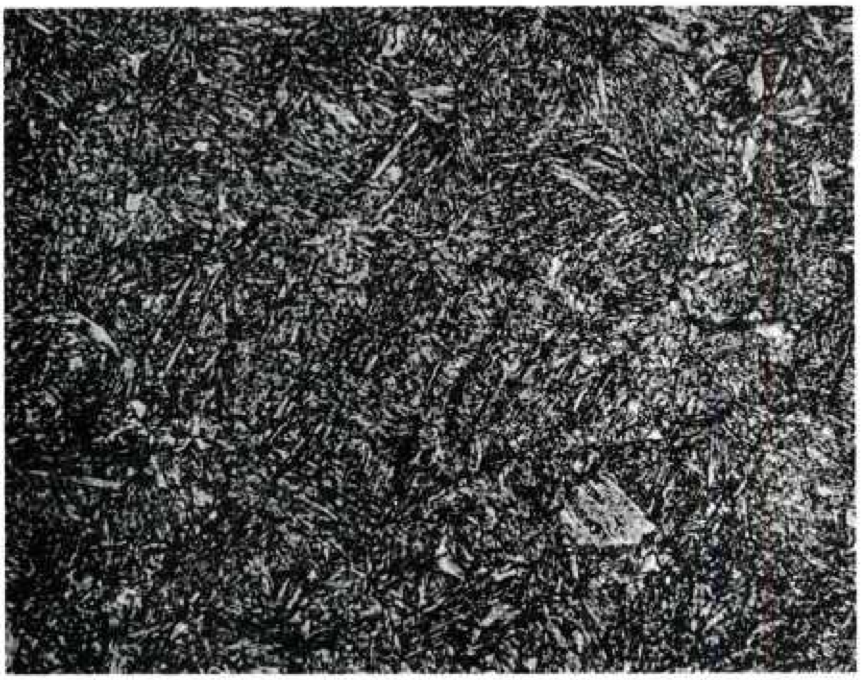


250X

Figure 21. Representative Section of a P/M Forged 4640 Accelerator Showing A Generally Low Level of Inclusions and A Clean Microstructure.



100X



500X

Figure 22. Microstructure of P/M Forging. Oil Quenched from 1550°F Tempered at 1150° to Rockwell C30.

4.0 COST ANALYSIS

The cost for production of the accelerator by the minimum deformation P/M forging process on a hydraulic press was derived from a previous program[1]. The cost estimates for compacting and sintering preforms were compiled after consultation with TRW's Supermet Division (a commercial powder metallurgy operation) using input from the Reference (1) program. A production rate of 50 pieces per hour was estimated for compacting preforms. The estimated rate was based on hand loading and unloading the preform die since the accelerator preform configuration does not lend itself to automatic press handling which is the normal commercial practice. Sintering costs were based on the use of a furnace with a 400 pound per hour capacity using a single operator on a 100% basis. Raw material costs were updated by current quotations for quantities in keeping with the lot size being estimated. A \$0.15/pound cost was added for blending powder lubricant and graphite by the powder manufacturer.

For the analysis, a production rate of fifty (50) pieces per hour was assumed for both the hydraulic and mechanical presses, with a two-shift operation of 3600 hours per year at 70% usage. The cost projection is the same for both presses with the exception of capital investment, amortization (14 years) and the higher yield derived from greater accuracy of the mechanical press.

The yield of the hydraulic press was assumed to be 90% of that of the mechanical press which was used for baseline data. The 90% yield was based on the assumption that improvements in the yield of the hydraulic press could be obtained by modification of the press cycle. The modification would include controls to provide a constant time at which the forging would be held at pressure during the forging cycle.

A capital cost of \$100,000 for a hydraulic press was assumed. A suitable press was defined as one of standard design capable of forging the accelerator and having a nominal tonnage rating of 200 to 400 tons with a closing speed of 50 to 100 inches per minute. A mechanical press cost of \$100,000 was assumed also based on the use of an available press of standard design. A standard design crank press of 250 to 500 ton capacity would require modification to prevent overloading the tooling. The modifications which could be incorporated into the press on the forging die set would consist primarily of a hydraulic cushion to provide constant forging pressure. Cost of modification which would be similar to the die set built for the Task 2 effort was assumed to be \$10,000. Modification and capital costs were amortized over a 14-year period based on a production rate of 50 pieces per hour for 3600 hours per year at 70% efficiency. When amortized over a 14-year period, the capital costs for the hydraulic and mechanical presses were equal at \$0.06 per piece.

---

(1) F. T. Lally, I. J. Toth and J. D. Benedetto, "Forged Metal Powder Products", U. S. Army Technical Report SWERR-TR-72-51.

Tooling costs of $5000 per set of perishable tooling, and a tool life of 10,000 pieces was estimated. This estimate was based on measurements of the tooling used during the program to produce approximately 1000 forgings with no visible signs of wear and deterioration.

The cost breakdown for the hydraulic and mechanical presses are compared in Table 4. The data show no decided preference for either type of equipment. An improved die life could be expected from tooling used in the mechanical press because the higher speed of the crank press results in less heating of the die and a lower ejection force. Additionally, maintenance costs would be expected to be lower with the mechanical press because of the more straightforward design of the crank press.

Cost comparisons for 1000, 10,000 and 100,000 pieces are summarized and compared in Table 5. The cost advantages of the P/M forging process lie in the higher material utilization and elimination of machining operations achieved by the precision of the P/M forging process. It is noteworthy that machining and finishing costs of the P/M version of the accelerator represent 75% of the total cost of production. These figures indicate that substantial cost reductions may be achieved by redesigning the accelerator as a precision forging and by eliminating additional machining operation by a more complex tool design.

TABLE 4

COST COMPARISON FOR P/M FORGING THE ACCELERATOR
IN HYDRAULIC VERSUS MECHANICAL PRESSES
BASED ON A 1000 PIECE LOT

	Hydraulic Press			Mechanical Press		
	Hrs/Pc	$/Pc	Set-Up Hrs.	Hrs/Pc	$/Pc	Set-Up Hrs
Compact	.0222	0.57	4.0	.0200	0.56	4.0
Sinter	.0025	0.07	-	.0025	0.06	-
Forge	.0222	0.57	3.0	.0200	0.56	3.0
Heat Treat	.0800	2.00	-	.0800	2.00	-
Sand Blast	.0300	0.75	-	.0300	0.75	-
Machine	.2864	7.16	16.6	.2864	7.16	16.6
Finish	.1892	4.73	1.1	.1892	4.73	1.1
Material	-	0.31	-	-	0.31	-
Subtotal	.6281	16.16	24.7	.6261	16.13	24.7
Tooling $/Pc		0.50			0.50	
Capital Cost (Forging Press Only)		0.06			0.06	
Totals (Including Set-Up Hrs.)		17.34			17.31	

Standard Hours are Multiplied by $25 To Convert to $/Pc.

TABLE 5

COST PER PIECE COMPARISON OF P/M FORGED ACCELERATORS
HYDRAULIC PRESS FORGED VS MECHANICAL PRESS FORGED

Item	Hydraulic Press Forging			Mechanical Press Froging		
	1,000 Pc	10,000 Pc	100,000 Pc	1,000 Pc	10,000 Pc	100,000 Pc
Material Cost	0.31	0.28	0.27	0.31	0.28	0.27
Forge & HT	3.96	3.83	3.81	3.93	3.78	3.76
Machine	7.16	6.78	6.75	7.16	6.78	6.75
Finish	4.73	4.72	4.70	4.73	4.72	4.70
Totals	16.16	15.61	15.53	16.13	15.28	15.48

Tooling, capital costs and inspection are not included.

An hourly rate of $25/hr. is assumed for both presses.

5.0 SURVEY OF COMPONENTS AND FACILITY REQUIREMENTS

This task involved a survey of weapons components which can beneficially be forged by the P/M forging process. The task was carried out in cooperation with the Army and included a survey of a number of components of the M85-50 caliber machine gun. Part drawings for the components were furnished by the Army. The survey identified those components which could benefit by P/M processing and classified components by size, complexity and recommended P/M processing procedures.

The components were tabulated in terms of material costs, plan area and type of forging recommended. Included in the tabulation are estimates of the degree of forging difficulty and cost reduction potential which could be realized by converting the part to P/M processing. A majority of the components were 1.5 in^2 or less in plan area, and were judged ideal for forging by the minimum deformation process.

Components of 1.5 in^2 or less were classified separately because these parts can be forged from a minimum deformation type preform in a single blow in a 50-ton crank press. Presses of this type represent a moderate capital investment on the order of $15,000 and require minimal modification for adaptation to P/M precision forging. The major modification would be to make provisions for an ejection mechanism to recover the forging from the die. If care in processing is exercised to prevent forging of overweight preforms, no other modification of the press would be needed.

Components in this category are tabulated in Table 6. These are minimum deformation type forgings which would be converted to the 4600 material composition for P/M forging. The minimum deformation preforms for this group of candidate forgings could be processed on a small powder compacting press of 50 tons capacity. Alternately, the preforms could be purchased from a commercial P/M vendor as unsintered compacts. Because of their small size, preforms could be handled and shipped in the green unsintered condition without difficulty.

The recommended furnace for heating preforms for forging would be the rotary hearth type. This type of furnace could be loaded and unloaded by the forging press operator. If desired, components could be forged directly from the furnace to eliminate the sintering step.

Some typical components of this type are tabulated in Table 7. The information includes a sketch of the component with the remaining machining and finishing operations indicated. All components in the category are excellent candidates for minimum deformation forging of P/M forgings.

Minimum development effort would be required for the preforms because the configurations are flat in the direction of pressing.

TABLE 6

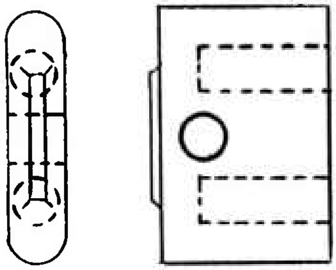
CANDIDATE COMPONENTS FOR P/M FORGING

MINIMUM DEFORMATION PROCESS ON A 50 TON CRANK PRESS

Part Name	Part No.	Mat'l Cost $	Plan Area in^2	Type of Forging Operation	Mat'l	Hardness R_c	Difficulty	Cost Savings Potential
Barrel, Interlock	7791278	.01	.26	Min. Def.	4340	42-46	Simple	Excellent
Stud, Positioning Front	7793019	.02	.31	" "	1020	None	Complex	"
Stud, Positioning Rear	7793020	.02	.31	" "	1020	"	"	"
Cam, Latch	7793083	.01	.18	" "	8620	15N-85	Simple	Good
Pawl, Belt Retaining	8448226	.02	.37	" "	4340	40-45	"	Good
Detent, Cover	7793132	.03	.40	" "	4340	38-42	"	"
Latch, Back Plate	8448210	.03	.75	" "	4140	32-36	"	"
Pawl, Cartridge Stop	7793222	.02	.75	" "	4340	43-48	"	"
Pawl, Cartridge Guide	7793244	.03	1.00	" "	4140	42-47	"	"
Selector, Rate	7793074	.05	1.05	" "	4140	43-48	Intermediate	"
Latch, Cover	7793230	.03	1.55	" "	8620	15N-85	Simple	"
Ramp Guide, Cartridge	7793232	.13	1.50	" "	4140	35-40	"	"

TABLE 7

TYPICAL CANDIDATE COMPONENTS FOR P/M FORGING



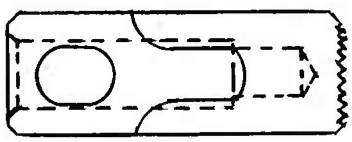
Detent, Cover, P/N 7793132

Forge Complete Except Drill 2 Flat Bottom Holes. Drill 1 Cross Hole.

.40 In^2 Plan Area
.091 Lbs. - 0.3 Dollar/Piece Material Cost.

15 Tons Force - Forge.

12 Tons Force - Compact

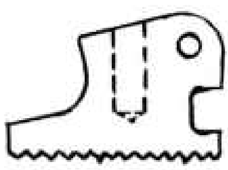


Selector, Rate, P/N 7793674

Forge Complete Except Drill & Ream .346 Dia. Hole and Machine Rachet Grooves.

1.05 In^2 Plan Area
.16 Lbs. - .05 Dollar/Piece Material Cost.

42 Tons Force - Forge.
31 Tons Force - Compact

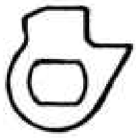


Latch, Backplate

Forge Complete Except Drill .125 Hole Through
Drill .187 Hole

Machine Ratchet Grooves

.75 In^2 Plan Area.
.4 Lbs - .03 Dollar/Piece Material Cost.
30 Tons Force - Forge
22 Tons Force - Compact.

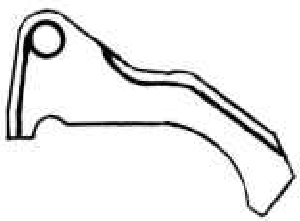


Cam, Latch P/N 7793083

Forge Complete

.18 In^2 Plan Area.
.02 Lbs. - .01 Dollar/Piece

7 Tons Force - Forge
5 Tons Force - Compact



Pawl, Cartridge Stop, P/N 7793222

Forge Complete Except Drill
Cross Hole.
Chamfer 2 Places.

.75 In^2 Plan Area
.08 Lbs. - $.02 Dollar/Piece
Material Cost.

30 Tons Force - Forge.
22 Tons Force - Compact.

Pawl, Belt Retaining, P/N 8448226

Forge Complete Except Drill and
Ream Hole (.157) Dia.

.37 In^2 Plan Area
.05 Lbs. - .02 Dollar/Piece
Material Cost

15 Tons Force - Forging
11 Tons Force - Compact

Some larger components are tabulated in Table 8. The tabulation also includes some components which require additional development for P/M application, some of which are candidates for isothermal forging.

The first six components listed in Table 8 are more challenging candidates for P/M forging than the components tabulated in Table 7. Because of their larger size and complexity, these should be considered as second generation candidates and their conversion to P/M forging would require additional development.

The cover, P/N 7793151 was the subject of a program to investigate isothermal forging of prealloyed steel powder[2]. This same processing is applicable to the production of the guide link, P/N 11010133. The isothermal forging process is not, however, in a state of development comparable to that of the minimum deformation P/M forging process.

---

(2) F. T. Lally, I. J. Toth "Isothermal Forging of Precision Metal Powder Components", TRW Inc., July 1973

TABLE 8

CANDIDATE COMPONENTS FOR P/M FORGING
VARIOUS PROCESSES - VARIOUS SIZE PRESSES

Part Name	Part No.	Mat'l Cost $	Plan Area In^2	Type Forging Operation	Mat'l	Hardness R_c	Difficulty	Cost Savings Potential
Cylinder, Time Delay	7793076	.30	1.92	Min. Def.	-	48-51	Difficult	Fair
Disconnector	7793220	.08	2.15	" "	4340	43-46	Complex	Excellent
Slide, Belt Feed	8448227	.07	2.81	" "	8620	15N-83	"	"
Housing, Return Feed	7793225	.12	3.13	" "	4340	30-35	"	"
Housing, Plunger	7793209	.34	4.0	" "	4340	48-52	"	Fair
Block, Trunnion	7793632	.60	7.73	" "	8620	22-28	Intermediate	Excellent
Shaft, Cylinder	7793079	.02	.30	Extrude	4340	45-50	Simple	Fair
Trigger Assembly			Possible but needs more information.					
Lever Assembly	7793211		Possible but needs more development.					
Tray Feed	7793049		Not suitable for P/M forging.					
Guide Link	11010133	.12	4.57	Isothermal	4140 8640	36-40	Complex	Excellent
Cover	7793151	-	35.0	"	4340	36-40	"	"

6.0 SUMMARY AND CONCLUSIONS

The program objective was to determine the feasibility of P/M forging on existing forge shop equipment and to define the required modifications. The M-85 accelerator produced by minimum deformation forging was used as the demonstration component. The process and tooling for forging the accelerators had been developed on a prior program.

The minimum deformation tooling, die and punches were resized to correct minor dimensional discrepancies. The tooling was then adapted for service in a mechanical crank-type press and a steam drop forging hammer. A die set was constructed for this purpose with provisions to absorb excess force by means of hydraulic cushions, provide accurate alignment between punches and the die, and to provide an ejection mechanism for recovery of the completed forging.

The feasibility of producing the accelerator by P/M forging on a mechanical press was demonstrated by forging 50 pieces. Steam drop hammer forging was not attempted because program data indicated that hammer forgings would not meet the dimensional requirements of the part drawings.

A number of components for the M85-50 caliber machine gun were identified as potential candidates for P/M forging. The facilities and process requirements were defined for producing these components by P/M forging.

The mechanical crank-type press was found to be superior to the hydraulic press in terms of dimensional accuracy of the resultant forgings. The cost benefits of the mechanical press were shown to be marginally superior to the hydraulic press based on long term output of both types of equipment.

The utility of the hydraulic press, the mechanical crank press and the forging hammer for producing net or near-net P/M forgings was assessed. The mechanical press is best suited to producing small or intermediate forgings with plan areas up to about 10 in^2. When used for the production of no-draft forgings without flash, the press requires the incorporation of a hydraulic cushion to prevent overloading the tooling. The problem of incorporating a cushion becomes increasingly difficult as the size of the cushion increases. The need for a hydraulic cushion is then the major limitation to the use of a crank press for producing flashless forgings.

The hydraulic press was inferior to the crank press in terms of dimensional accuracy and while the yield could be expected to improve as a result of production experience, the yield could not be expected to match the crank press output. The hydraulic press is better suited to the production of somewhat larger or more complex configurations where its less

efficient production could be offset by the incorporation of more detail in the forging with consequent elimination of machining operations. It also seems obvious that components larger than about 15 to 20 in^2 should be produced by the isothermal forging process.

The forging hammer is limited to the production of P/M net forging with comparatively large dimensional tolerances. The hammer is suited to the production of large components which can tolerate draft angles. The advantages of the forging hammer would derive from the production of one-blow forgings with limited amount of flash and the increased efficiency of the hammer operation.

APPENDIX A

Dimensional Data Derived From Hydraulic Press-Forged Accelerators

(Dimensions Identified As Indicated In Figure 19)

Specimen No.	Forged Wt.Gms.	Forge Plane Dimensions "A"	"B"	"C"	Die Established Dimensions "D"	"F"	"G"	"E"
C 1	472.1	.985	.987	.693	2.510	.372	.372	.999
C 2	473.1	.987	.991	.696	2.507	.374	.376	.998
C 5	475.6	.990	.991	.700	2.519	.372	.324	.999
C 6	-	.990	.991	.703	2.522	.374	.376	1.001
C 7	497.6	1.016	1.016	.735	2.516	.373	.376	1.001
C 8	483.7	.998	1.000	.713	2.516	.372	.376	1.001
C 9	-	.996	.997	.709	2.516	-	-	.999
C10	475.8	.983	.990	.701	2.516	.372	.377	1.001
C11	486.4	1.003	1.003	.713	2.517	.374	.377	1.002
C12	477.8	.985	.987	.696	2.516	.373	.377	.999
C13	-	1.000	1.002	.699	2.508	.371	.373	.994
C14	473.5	.990	.992	.692	2.513	.372	.376	1.000
C15	473.8	.990	.992	.692	2.515	.374	.377	.999
C16	477.4	.994	.996	.699	2.516	.373	.376	.999
C17	476.6	.994	.995	.698	2.515	.373	.376	1.000
C18	475.2	.995	.997	.694	2.513	.372	.376	1.000
C19	474.9	.994	.995	.691	2.517	.374	.377	1.000
C20	480.8	1.001	1.003	.704	2.518	.373	.377	1.000
C21	477.1	1.000	1.001	.699	2.513	.372	.376	1.000
C22	478.6	.999	1.001	.699	2.515	.372	.376	1.000
C23	475.3	.994	.995	.690	2.518	.374	.376	1.000
C24	-	.999	1.002	.706	2.517	.372	.375	.999
C25	476.2	.996	.999	.701	2.509	.372	.376	.998
C26	480.8	.998	1.000	.700	2.508	.370	.374	.997
C27	477.1	.999	1.000	.700	2.510	.371	.375	.998
C28	483.0	1.013	1.012	.708	2.510	.372	.376	.999
C29	474.2	1.004	.999	.697	2.511	.374	.374	.999
C30	481.1	1.005	1.005	.707	2.510	.373	.374	1.000
C31	482.2	1.010	1.012	.710	2.512	-	-	.998
C32	473.3	.994	.994	.695	2.512	.372	.376	.997

APPENDIX A

Dimensional Data Derived From Hydraulic Press-Forged Accelerators

(Dimensions Identified As Indicated In Figure 19)

Specimen No.	Forged Wt.Gms.	Forge Plane Dimensions "A"	"B"	"C"	Die Established Dimensions "D"	"F"	"G"	"E"
C33	476.6	1.001	1.000	.697	2.511	.371	.375	.998
C34	474.8	.998	.999	.693	2.512	.374	.375	.999
C35	475.9	.998	.996	.695	2.517	.373	.375	.999
C37	476.6	.996	.996	.698	2.516	.374	.376	.999
C38	475.8	1.001	1.001	.697	2.513	.373	.373	.999
C39	477.6	1.000	1.002	.699	2.513	.373	.375	.999
C40	478.0	1.002	1.002	.698	2.517	.372	.376	1.000
C41	476.0	1.000	1.000	.697	2.512	.373	.376	.999
C42	478.8	1.004	1.006	.704	2.516	.372	.376	1.000
C43	477.3	1.000	1.002	.696	2.523	.377	.378	1.001
C44	478.4	1.004	1.005	.700	2.513	.374	.376	1.000
C45	470.5	.986	.988	.692	2.505	.373	.376	.998
C46	480.0	1.001	1.003	.709	2.506	.373	.376	.998
C47	-	.992	.993	.702	2.523	.373	.379	1.000
C48	474.5	.991	.992	.696	2.517	.373	.377	1.000
C50	-	.992	.990	.695	2.524	.375	.377	1.001
C51	-	1.000	.999	.700	2.518	.374	.378	.999
C52	474.3	.990	.990	.692	2.526	.375	.379	1.004
C53	475.3	.992	.991	.697	2.523	.377	.380	1.003
C54	477.9	.997	.996	.701	2.522	.374	.378	1.002
C55	475.6	.991	.990	.697	2.522	.374	.377	1.004
C56	477.9	.997	.997	.700	2.528	.374	.378	1.004
C57	472.5	.992	.991	.688	2.523	.376	.378	1.004
C59	473.2	.992	.992	.696	2.528	.376	.378	1.003
C60	477.8	.997	.997	.696	2.529	.375	.377	1.003
C61	475.2	.997	.996	.697	2.525	.375	.377	1.002
C62	478.8	1.008	1.007	.705	2.520	.373	.377	1.002
C63	480.8	1.006	1.010	.703	2.523	.374	.377	1.002
C64	478.3	.998	.999	.698	2.529	-	-	1.003
C65	476.2	.998	.999	.694	2.529	.374	.377	1.003
C66	483.0	1.004	1.005	.706	2.522	.375	.377	1.002
C67	476.0	.993	.993	.694	2.525	.373	.379	1.003
C68	469.5	.988	.988	.681	2.524	.376	.376	1.004
C69	479.8	1.003	1.001	.700	2.536	.374	.377	1.004

APPENDIX A

Dimensional Data Derived From Hydraulic Press-Forged Accelerators

(Dimensions Identified As Indicated In Figure 19)

Specimen No.	Forged Wt.Gms.	Forge Plane Dimensions "A"	"B"	"C"	Die Established Dimensions "D"	"E"	"F"	"G"
C71	471.3	.993	.994	.687	2.530	1.003	.377	.378
C72	478.4	.996	.998	.701	2.524	1.004	.375	.376
C73	485.5	1.012	1.015	.714	2.521	1.003	.374	.377
C74	485.5	1.014	1.013	.714	2.525	1.004	.377	.375
C75	471.7	.996	.994	.686	2.522	1.004	.378	.375
C76	473.3	1.000	1.000	.690	2.523	1.003	-	-
C77	427.9	.994	.994	.688	2.524	1.005	.376	.377
C80	475.5	.984	.985	.681	2.524	1.005	.373	.377
C83	-	.991	.992	.695	2.524	1.005	.374	.380
C84	472.5	.996	.995	.690	2.524	1.004	.375	.376
C85	470.6	.988	.986	.688	2.528	1.005	.375	.377
C86	473.4	.993	.992	.692	2.527	1.004	.374	.377
C87	472.6	.992	.994	.690	2.521	1.004	.376	.376
C88	473.9	.993	.994	.690	2.524	1.004	.376	.377
C90	474.6	.993	.994	.691	2.528	1.005	.375	.377
C91	478.1	1.000	1.001	.699	2.527	1.005	.375	.376
C92	474.6	.995	.994	.692	2.522	1.005	.325	.376
C93	476.3	.998	.998	.694	2.526	1.005	.376	.376
C94	476.2	.998	.998	.694	2.527	1.003	.376	.376
C95	476.9	.998	.999	.694	2.527	1.004	.376	.376
C96	486.0	1.007	1.006	.712	2.522	1.005	.375	.376
C97	476.2	1.002	1.002	.694	2.522	1.004	.374	.377
C98	476.0	.997	.997	.693	2.524	1.004	.377	.377
C99	476.0	.998	.999	.692	2.525	1.004	.378	.377
C100	476.1	1.000	1.000	.693	2.529	1.006	.376	.377
C101	471.8	.991	.994	.688	2.529	1.006	.373	.380
C103	478.5	1.004	1.003	.697	2.524	1.004	.377	.378
C104	473.1	.994	.996	.687	2.527	1.004	.374	.377

APPENDIX B

Dimensional Data Derived From Mechanical Press-Forged Accelerators

(Dimensions Identified As Indicated In Figure 19)

Specimen No.	Forged Wt. Gms	Forge Plane Dimensions			Die Established Dimensions			
		"A"	"B"	"C"	"D"	"F"	"G"	"E"
701	472.5	1.023	1.023	.716	2.520	.995	.370	.372
707	471.2	.997	1.003	.692	2.513	.996	.371	.373
716	469.6	.998	1.002	.691	2.518	.996	.371	.373
719	473.7	1.004	1.004	.692	2.515	.995	.371	.372
820	466.8	1.002	1.004	.691	2.519	.996	.370	.373
722	469.5	1.011	1.008	.701	2.517	.996	.370	.373
729	471.6	1.006	1.007	.699	2.518	.996	.373	.372
724	468.6	1.000	1.006	.695	2.517	.996	.371	.373
725	466.6	.998	1.001	.691	2.516	.996	.373	.373
734	468.2	.997	.999	.692	2.519	.996	.372	.372
735	474.8	1.013	1.016	.703	2.522	.996	.372	.373
737	464.2	.997	1.001	.689	2.520	.997	.370	.373
738	467.1	1.016	1.018	.709	2.521	.995	.371	.372
741	470.2	1.000	1.004	.692	2.520	.997	.372	.373
745	471.2	1.029	1.031	.723	2.519	.995	.371	.371
750	471.4	1.008	1.011	.700	2.515	.994	.372	.372
753	474.2	1.013	1.014	.704	2.520	.995	.372	.372
754	467.8	.991	.997	.687	2.517	.996	.371	.373
759	471.2	1.029	1.031	.721	2.522	.995	.371	.372
763	472.7	1.000	1.003	.695	2.521	.997	.373	.373
767	471.3	1.006	1.008	.698	2.522	.996	.374	.372
769	473.8	1.011	1.012	.696	2.52.	.996	.372	.372
773	475.9	1.007	1.009	.697	2.518	.997	.372	.371
779	471.4	1.001	1.001	.697	2.519	.997	.374	.371
782	474.4	1.011	1.013	.702	2.520	.996	.371	.372
793	474.7	1.006	1.008	.695	2.513	.996	.372	.371
799	475.8	1.006	1.005	.699	2.517	.996	.372	.373
800	471.6	1.003	1.004	.691	2.519	.996	.374	.373
806	477.0	1.021	1.022	.708	2.517	.995	.372	.372
811	463.1	.995	1.000	.692	2.521	.996	.370	.373
812	480.2	1.016	1.019	.707	2.522	.995	.371	.374
815	472.9	1.008	1.009	.699	2.517	.994	.373	.373
817	476.0	1.023	1.025	.711	2.525	.995	.372	.373
818	466.0	1.011	1.014	.701	2.519	.995	.370	.373
819	467.4	1.004	1.003	.693	2.518	.996	.372	.373

Note.

Over 50 accelerators were forged but only 39 accelerators were delivered to RIA. The balance, which were setup pieces, were considered scrap.

DISTRIBUTION

	Copies
A. Department of Defense	
Defense Documentation Center ATTN: TIPDR Cameron Station Alexandria, VA 22314	12
B. Department of the Army	
Commander U. S. Army Materiel Command	
ATTN: AMCRD-E	1
AMCRP-I	1
AMCQA-E	1
5001 Eisenhower Avenue Alexandria, VA 22333	
Commander U. S. Army Materiel Command Scientific and Technical Information Team - Europe ATTN: AMXST-STL Dr. Richard B. Griffin APO New York 09710	1
Commander U. S. Army Armament Command	
ATTN: DRSAR-IMP-W	1
DRSAR-IMP-W	1
DRSAR-LEP	1
DRSAR-SC	1
DRSAR-QAE	1
Rock Island, IL 61201	
Director U. S. Army Materials and Mechanics Research Center ATTN: AMXMR-M Watertown, MA 02172	1
Director U. S. Army Maintenance Management Center ATTN: AMXMD-A Lexington, KY 40507	1

DISTRIBUTION

	Copies
Commander U. S. Army Electronics Command ATTN: AMSEL-PP/I/IM Fort Monmouth, NJ 07703	1
Commander U. S. Army Missile Command ATTN: AMSMI-IIE AMSMI-PRT Redstone Arsenal, AL 35809	1 1
Commander U. S. Army Tank-Automotive Command ATTN: AMSTA-RK AMSTA-RCM.1 Warren, MI 48090	1 1
Commander U. S. Army Aviation Systems Command ATTN: AMSAV-ERE P. O. Box 209 St. Louis, MO 63166	1
Commander U. S. Army Troop Support Command ATTN: AMSTS-PLC 4300 Goodfellow Blvd. St. Louis, MO 63120	1
Commander Ballistic Missile Defense Systems ATTN: BNDSC-TS P. O. Box 1500 Huntsville, AL 35804	1
Project Manager Munition Production Base Mod Picatinny Arsenal Dover, NJ 07801	1
Commander Harry Diamond Laboratories ATTN: AMXDO-RCD 2800 Powder Mill Road Adelphi, MD 20783	1

DISTRIBUTION

	Copies
Director U. S. Army Industrial Base Engineering Activity ATTN: DRXIB-MT Rock Island Arsenal Rock Island, Il. 61201	2
Director USAMC Intern Training Center ATTN: AMXMC-ITC-PPE Red Riber Army Depot Texarkana, TX 75501	1
Commander U. S. Army Tropic Test Center ATTN: STETC-MO-A (Technical Library) APO New York 09827	1

DISTRIBUTION

	Copies
Commander Natick Development Center ATTN: AMXNL-EQ Kansas Street Natick, MA 01762	1
Commander U. S. Army Air Mobility R&D Labs ATTN: SAVDL-ST Fort Eustis, VA 23604	1
Commander Rock Island Arsenal	
ATTN: SARRI-AOE	1
SARRI-APP Mr. V. Long	1
SARRI-RLS	1
SARRI-RL	1
SARRI-RLP-L	2
Commander Watervliet Arsenal	
ATTN: SARWV-PPP-WP	1
SARWV-PPI-LAJ	1
SARWV-QA	1
Watervliet, NY 12189	
Commander Picatinny Arsenal	
ATTN: SARPA-MT-C	1
SARPA-QA-T-T	1
SARPA-C-C	1
Dover, NJ 07801	
Commander Edgewood Arsenal ATTN: SAREA-QA Aberdeen Proving Ground, MD 21010	1

AD__________ Accession No.__________ UNCLASSIFIED

CDR, Rock Island Arsenal — TRW, Inc.
Arsenal Operations Directorate — 23444 Euclid Avenue
Rock Island, Illinois 61201 — Cleveland, Ohio

CLOSED DIE FORGING OF POWDER METAL PREFORMS COMPARISON OF P/M FORGING SYSTEMS
Final Report, by F. T. Lally, TRW, Inc. and J. R. Russell, Rock Island Arsenal

Report AOD-TR-002, Jun 1976, 46 p incl. illus. and tables (Contract DAAA08-75-C-0070)
Unclassified Report.

The project was aimed at establishing the potential usefulness of existing standard forge shop equipment for producing precision powder metal (P/M) forgings. The accelerator for the M85 machine gun was used as the demonstration component. The minimum deformation type tooling for hydraulic press forging the accelerator was adapted for service in a mechanical crank type press and a steam drop forging hammer.

1. Powder Metal Forgings
2. M85 Accelerator
3. Minimum Deformation Tooling
4. Mechanical Crank Type Press

DISTRIBUTION
Copies obtainable from DDC

AD__________ Accession No.__________ UNCLASSIFIED

CDR, Rock Island Arsenal — TRW, Inc.
Arsenal Operations Directorate — 23444 Euclid Avenue
Rock Island, Illinois 61201 — Cleveland, Ohio

CLOSED DIE FORGING OF POWDER METAL PREFORMS COMPARISON OF P/M FORGING SYSTEMS
Final Report, by F. T. Lally, TRW, Inc. and J. R. Russell, Rock Island Arsenal

Report AOD-TR-002, Jun 1976, 46 p incl. illus. and tables (Contract DAAA08-75-C-0070)
Unclassified Report.

The project was aimed at establishing the potential usefulness of existing standard forge shop equipment for producing precision powder metal (P/M) forgings. The accelerator for the M85 machine gun was used as the demonstration component. The minimum deformation type tooling for hydraulic press forging the accelerator was adapted for service in a mechanical crank type press and a steam drop forging hammer.

1. Powder Metal Forgings
2. M85 Accelerator
3. Minimum Deformation Tooling
4. Mechanical Crank Type Press

DISTRIBUTION
Copies obtainable from DDC

AD__________ Accession No.__________ UNCLASSIFIED

CDR, Rock Island Arsenal — TRW, Inc.
Arsenal Operations Directorate — 23444 Euclid Avenue
Rock Island, Illinois 61201 — Cleveland, Ohio

CLOSED DIE FORGING OF POWDER METAL PREFORMS COMPARISON OF P/M FORGING SYSTEMS
Final Report, by F. T. Lally, TRW, Inc. and J. R. Russell, Rock Island Arsenal

Report AOD-TR-002, Jun 1976, 46 p incl. illus. and tables (Contract DAAA08-75-C-0070)
Unclassified Report.

The project was aimed at establishing the potential usefulness of existing standard forge shop equipment for producing precision powder metal (P/M) forgings. The accelerator for the M85 machine gun was used as the demonstration component. The minimum deformation type tooling for hydraulic press forging the accelerator was adapted for service in a mechanical crank type press and a steam drop forging hammer.

1. Powder Metal Forgings
2. M85 Accelerator
3. Minimum Deformation Tooling
4. Mechanical Crank Type Press

DISTRIBUTION
Copies obtainable from DDC

AD__________ Accession No.__________ UNCLASSIFIED

CDR, Rock Island Arsenal — TRW, Inc.
Arsenal Operations Directorate — 23444 Euclid Avenue
Rock Island, Illinois 61201 — Cleveland, Ohio

CLOSED DIE FORGING OF POWDER METAL PREFORMS COMPARISON OF P/M FORGING SYSTEMS
Final Report, by F. T. Lally, TRW, Inc. and J. R. Russell, Rock Island Arsenal

Report AOD-TR-002, Jun 1976, 46 p incl. illus. and tables (Contract DAAA08-75-C-0070)
Unclassified Report.

The project was aimed at establishing the potential usefulness of existing standard forge shop equipment for producing precision powder metal (P/M) forgings. The accelerator for the M85 machine gun was used as the demonstration component. The minimum deformation type tooling for hydraulic press forging the accelerator was adapted for service in a mechanical crank type press and a steam drop forging hammer.

1. Powder Metal Forgings
2. M85 Accelerator
3. Minimum Deformation Tooling
4. Mechanical Crank Type Press

DISTRIBUTION
Copies obtainable from DDC